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(12) **United States Patent**  
**Lahoud et al.**

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(54) **HOOKAH DEVICE**

(71) Applicant: **SHAHEEN INNOVATIONS HOLDING LIMITED**, Abu Dhabi (AE)

(72) Inventors: **Imad Lahoud**, Abu Dhabi (AE); **Mohammed Alshaiba Saleh Ghannam Almazrouei**, Abu Dhabi (AE); **Sajid Bhatti**, Abu Dhabi (AE); **Jeff Machovec**, Abu Dhabi (AE); **Clement Lamoureux**, Abu Dhabi (AE)

(73) Assignee: **Shaheen Innovations Holding Limited**, Abu Dhabi (AE)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

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**A24F 40/05** (2020.01)

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(52) **U.S. Cl.**

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(58) **Field of Classification Search**

None  
See application file for complete search history.

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*Primary Examiner* — Kelly M Gambetta

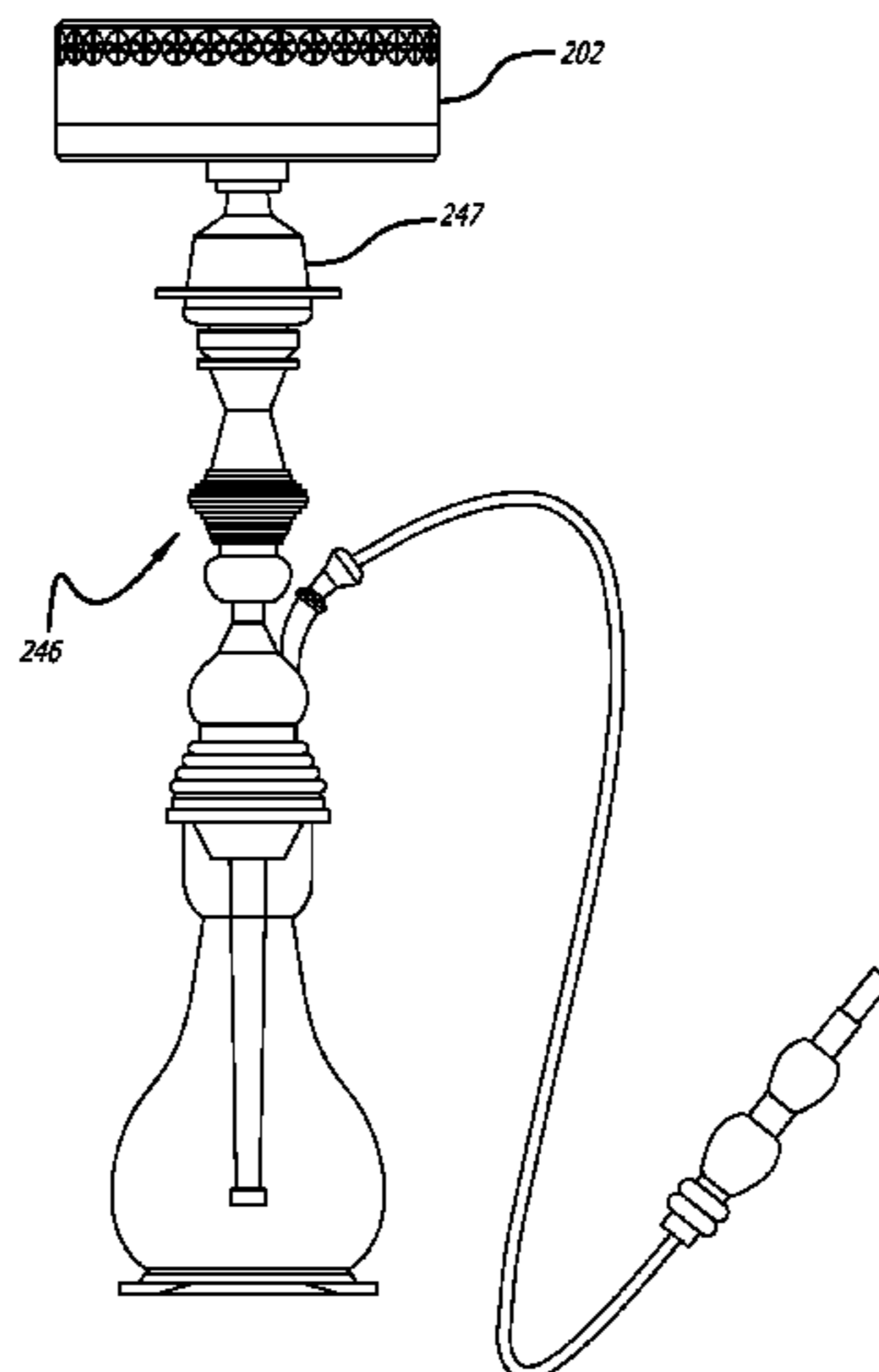
*Assistant Examiner* — Katherine A Will

(74) *Attorney, Agent, or Firm* — Amedeo F. Ferraro, Esq.

(57) **ABSTRACT**

A hookah device (202) which attaches to a hookah (246). The hookah device (202) comprises a plurality of ultrasonic mist generator devices (201) for generating a mist for inhalation by a user. The hookah device (202) comprises a driver device (202) which controls the mist generator devices (201) to maximize the efficiency of mist generation by the mist generator devices (201) and optimize mist output from the hookah device (202).

**19 Claims, 34 Drawing Sheets**



**Related U.S. Application Data**

application No. 17/065,992, filed on Oct. 8, 2020, which is a continuation-in-part of application No. 16/889,667, filed on Jun. 1, 2020, application No. 17/223,846 is a continuation-in-part of application No. 17/122,025, filed on Dec. 15, 2020, which is a continuation-in-part of application No. PCT/IB2019/060808, filed on Dec. 15, 2019, and a continuation-in-part of application No. PCT/IB2019/060810, filed on Dec. 15, 2019, and a continuation-in-part of application No. PCT/IB2019/060811, filed on Dec. 15, 2019, and a continuation-in-part of application No. PCT/IB2019/060812, filed on Dec. 15, 2019, application No. 17/223,846 is a continuation-in-part of application No. 17/220,189, filed on Apr. 1, 2021.

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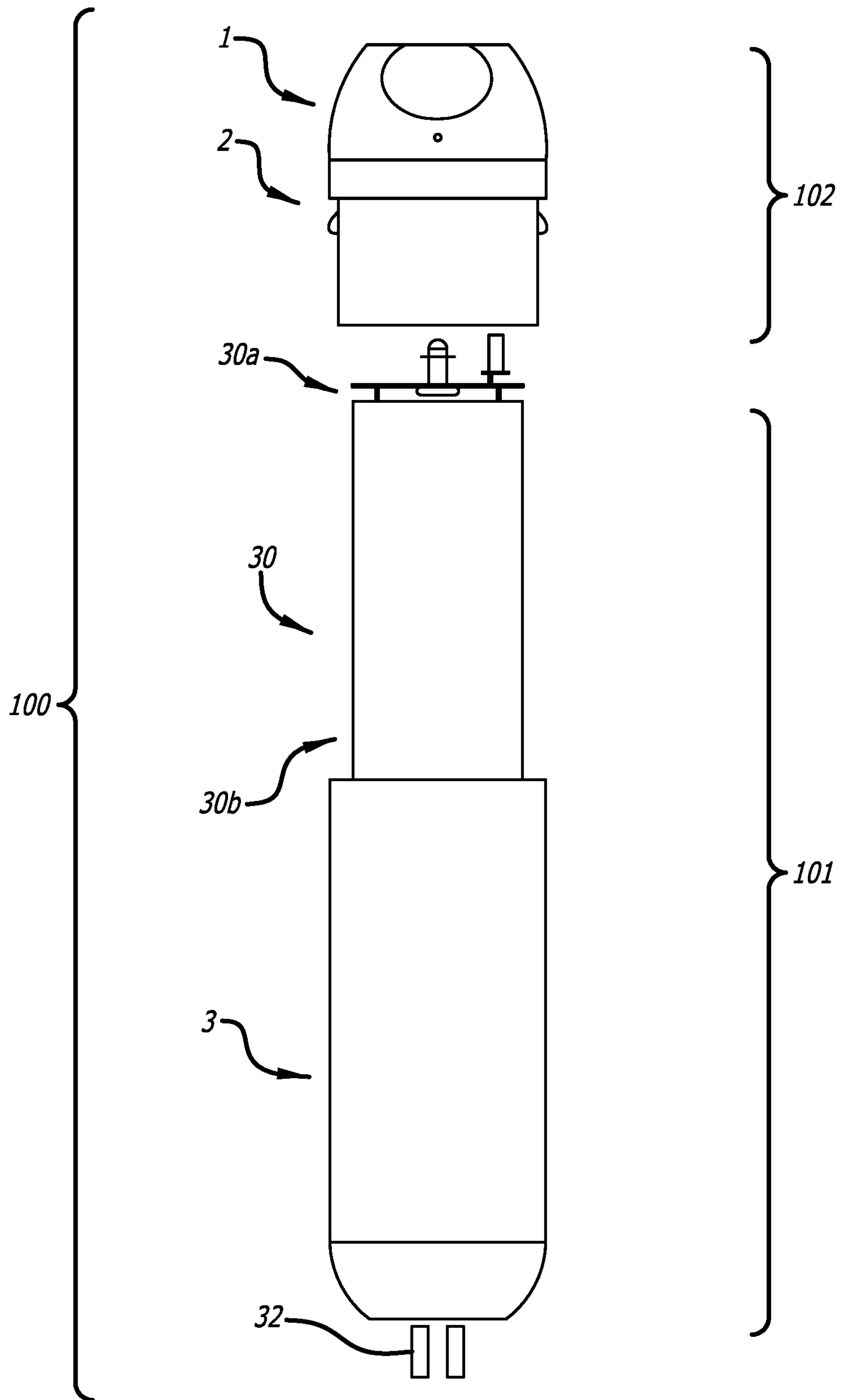


FIG. 1

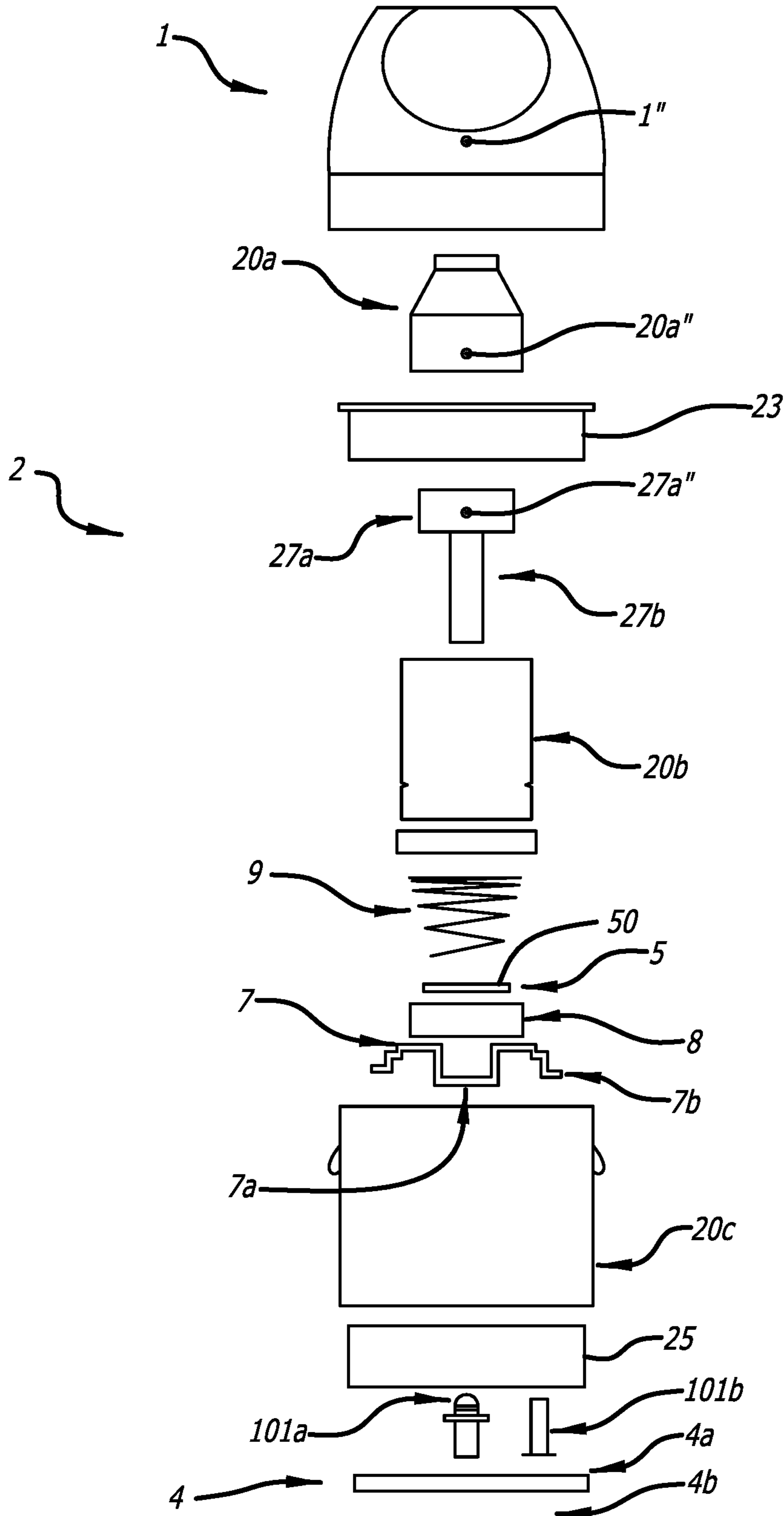


FIG. 2

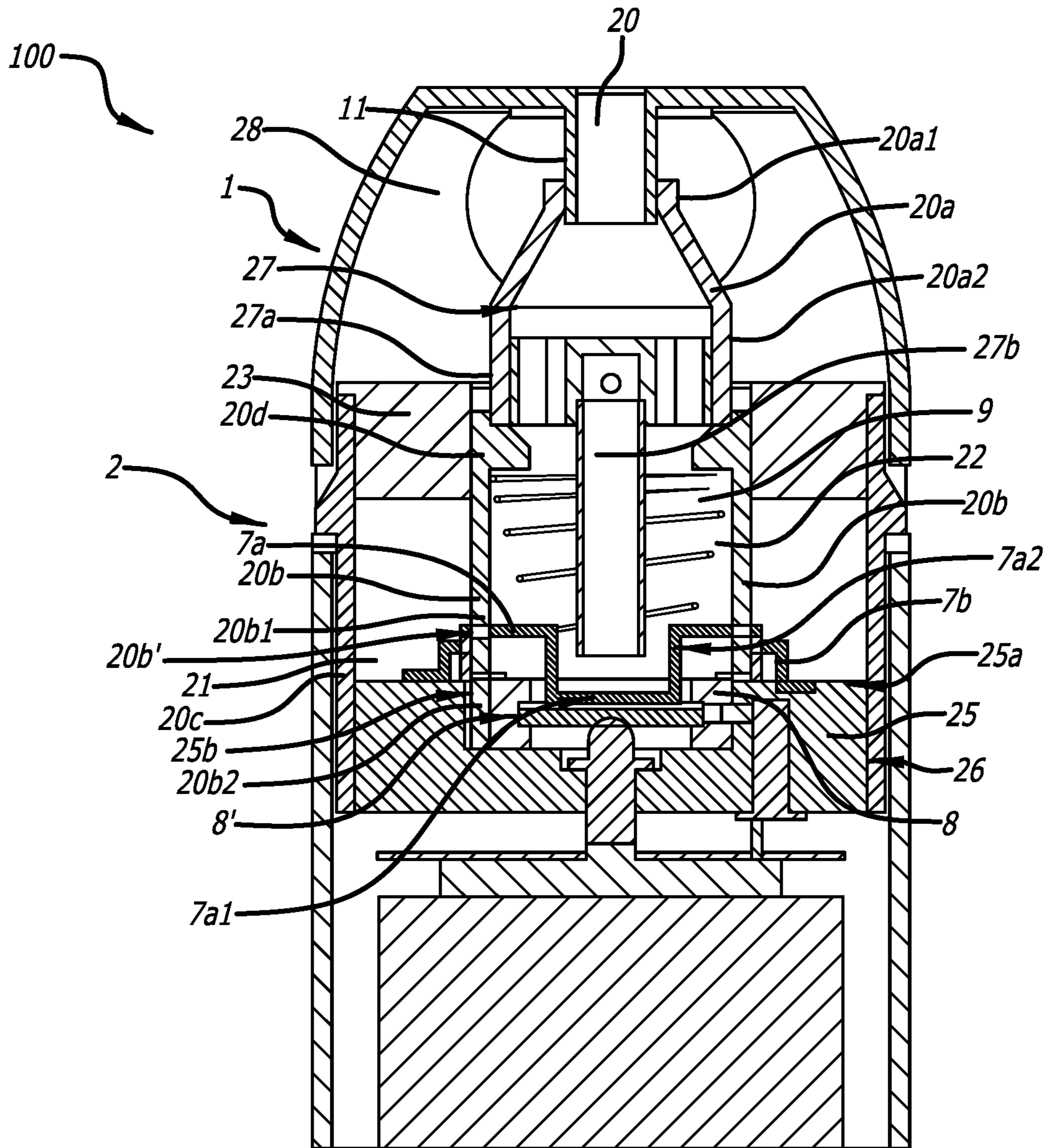


FIG. 3



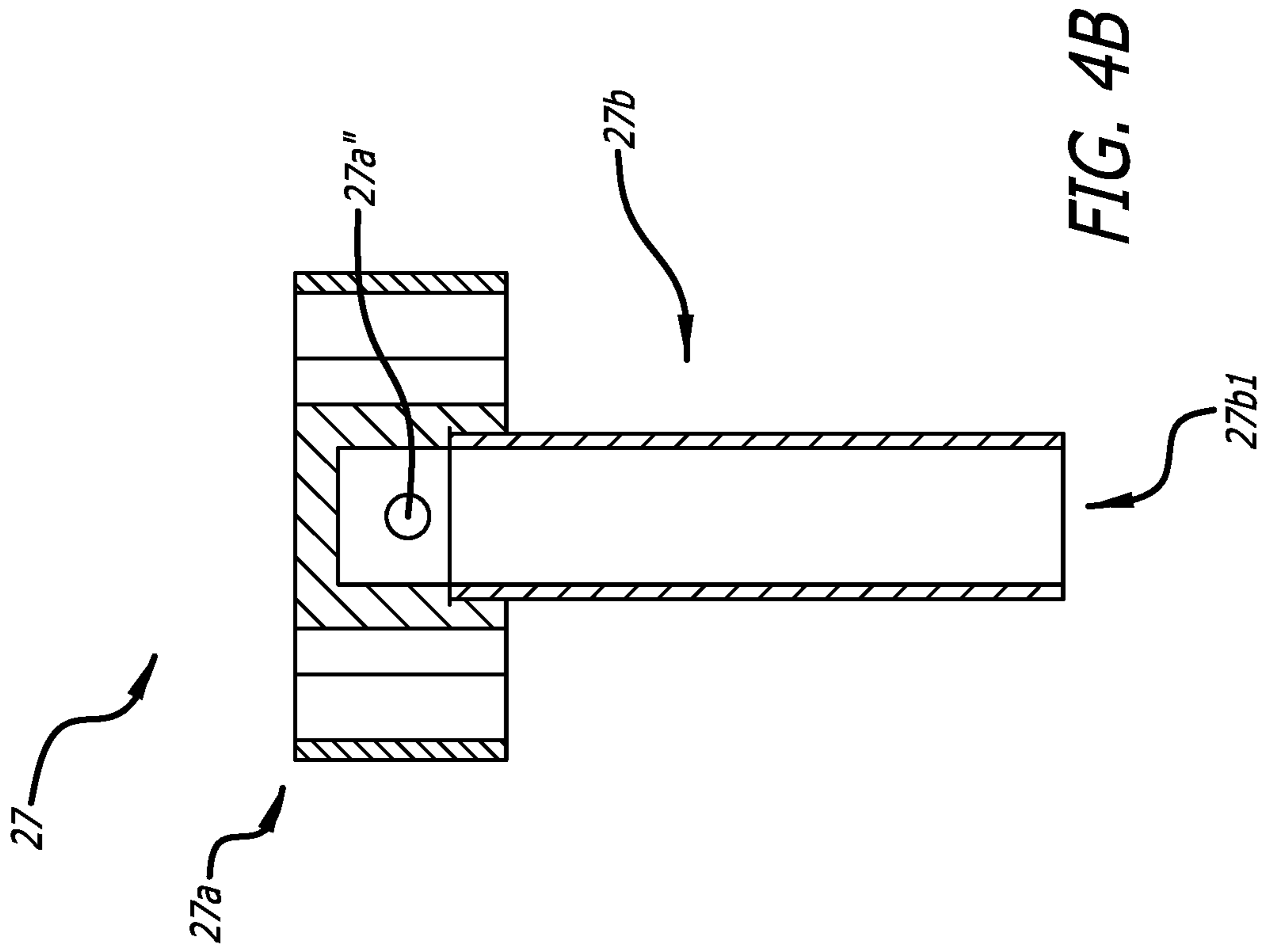


FIG. 4B

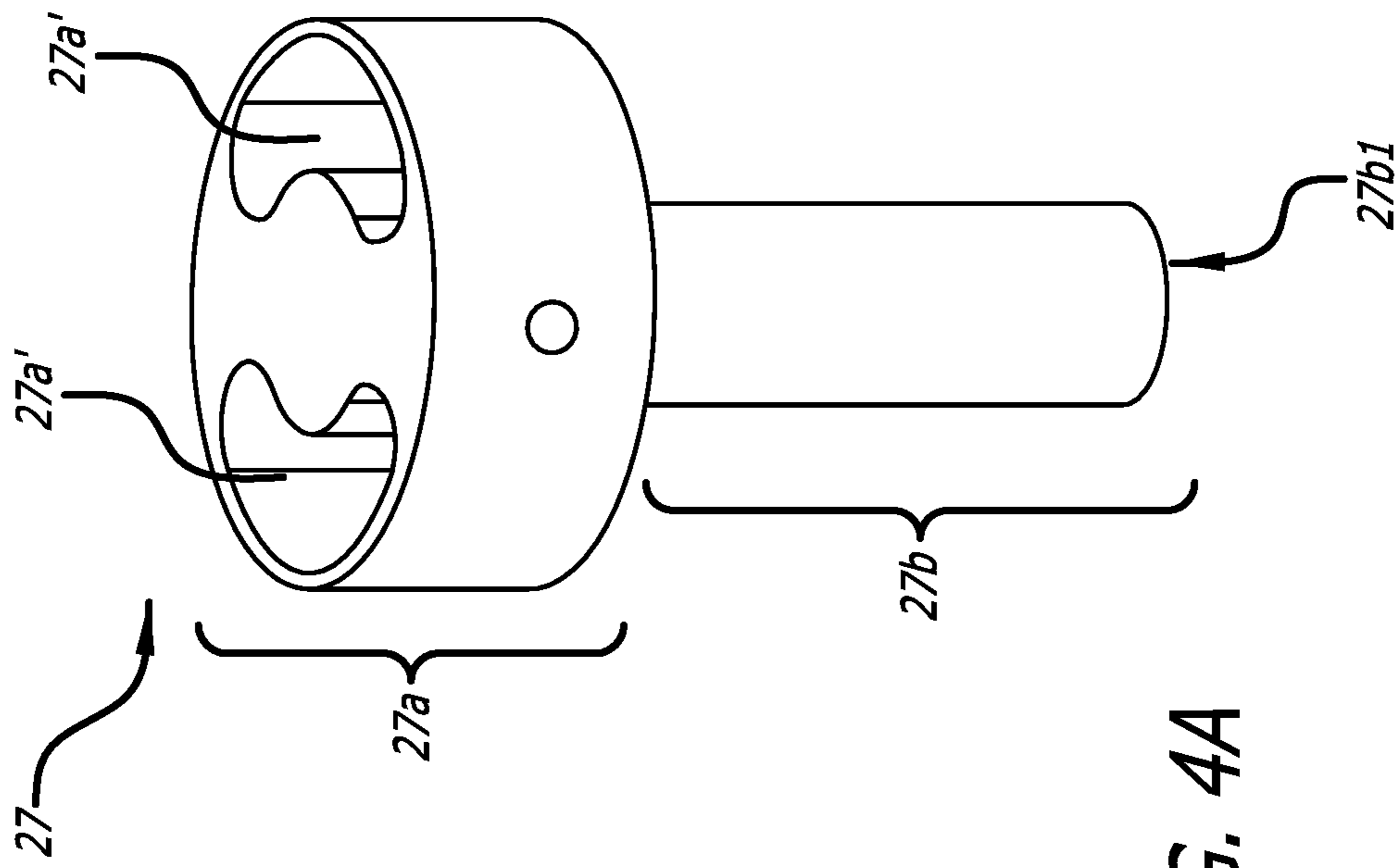
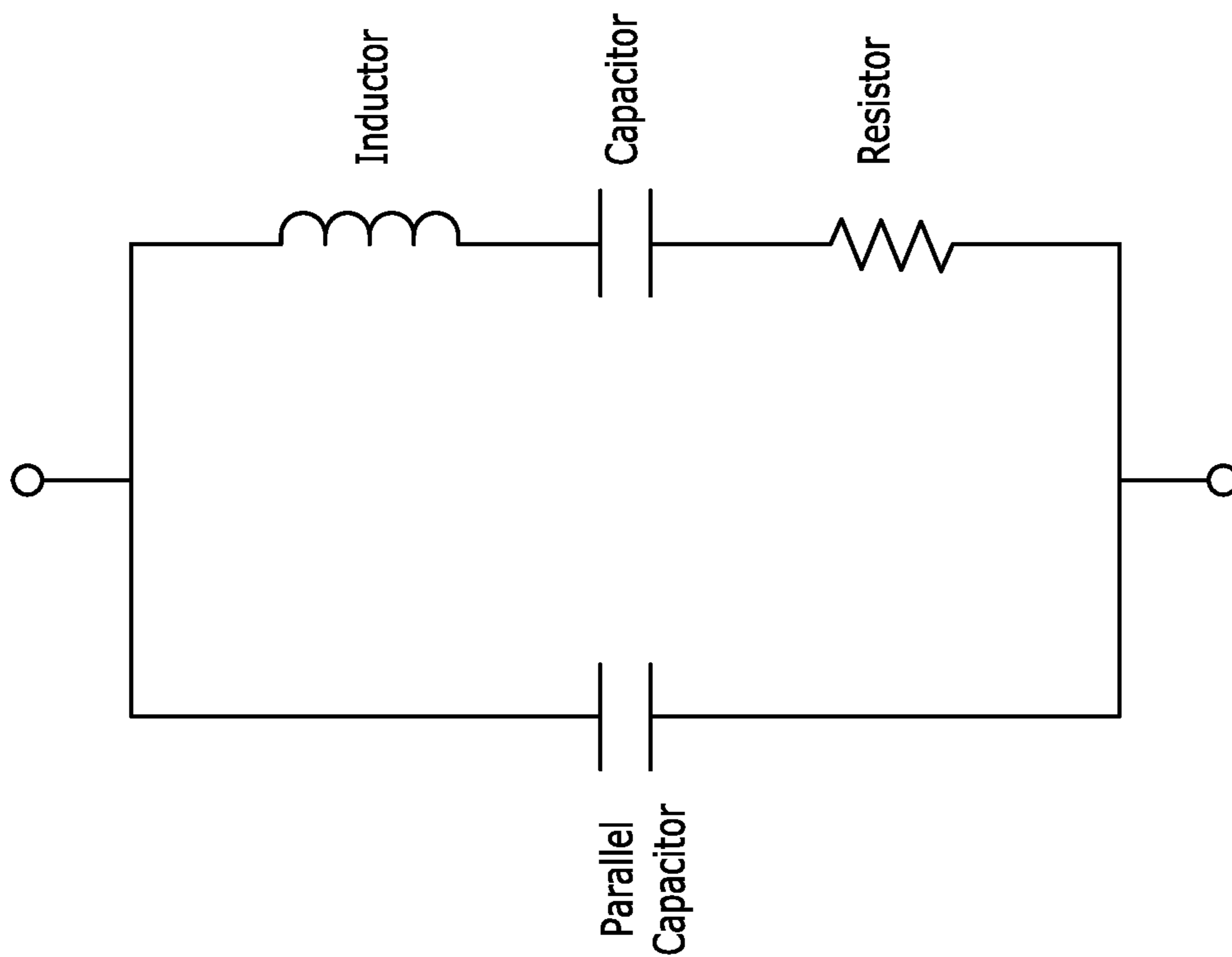
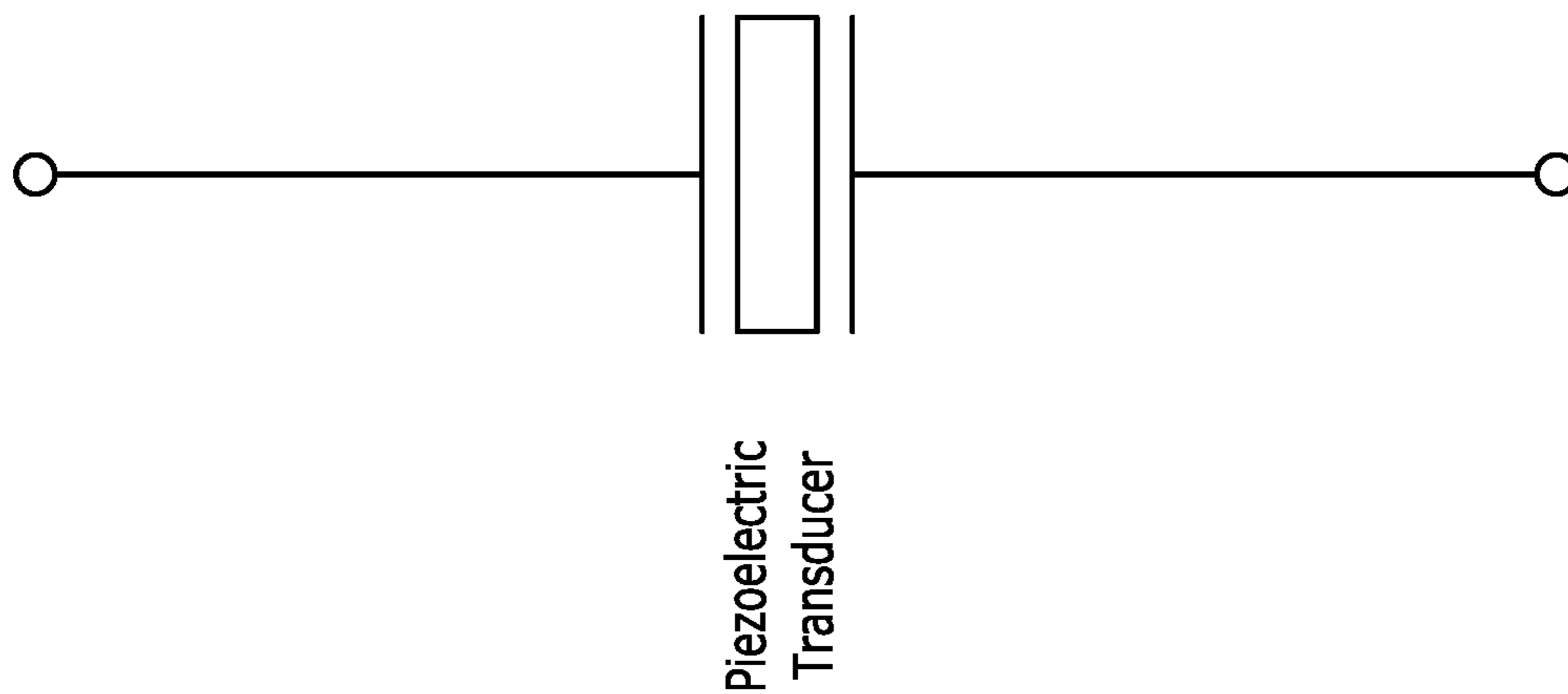


FIG. 4A



Components of Piezoelectric Transducer in a circuit



Piezoelectric Transducer

**FIG. 5**

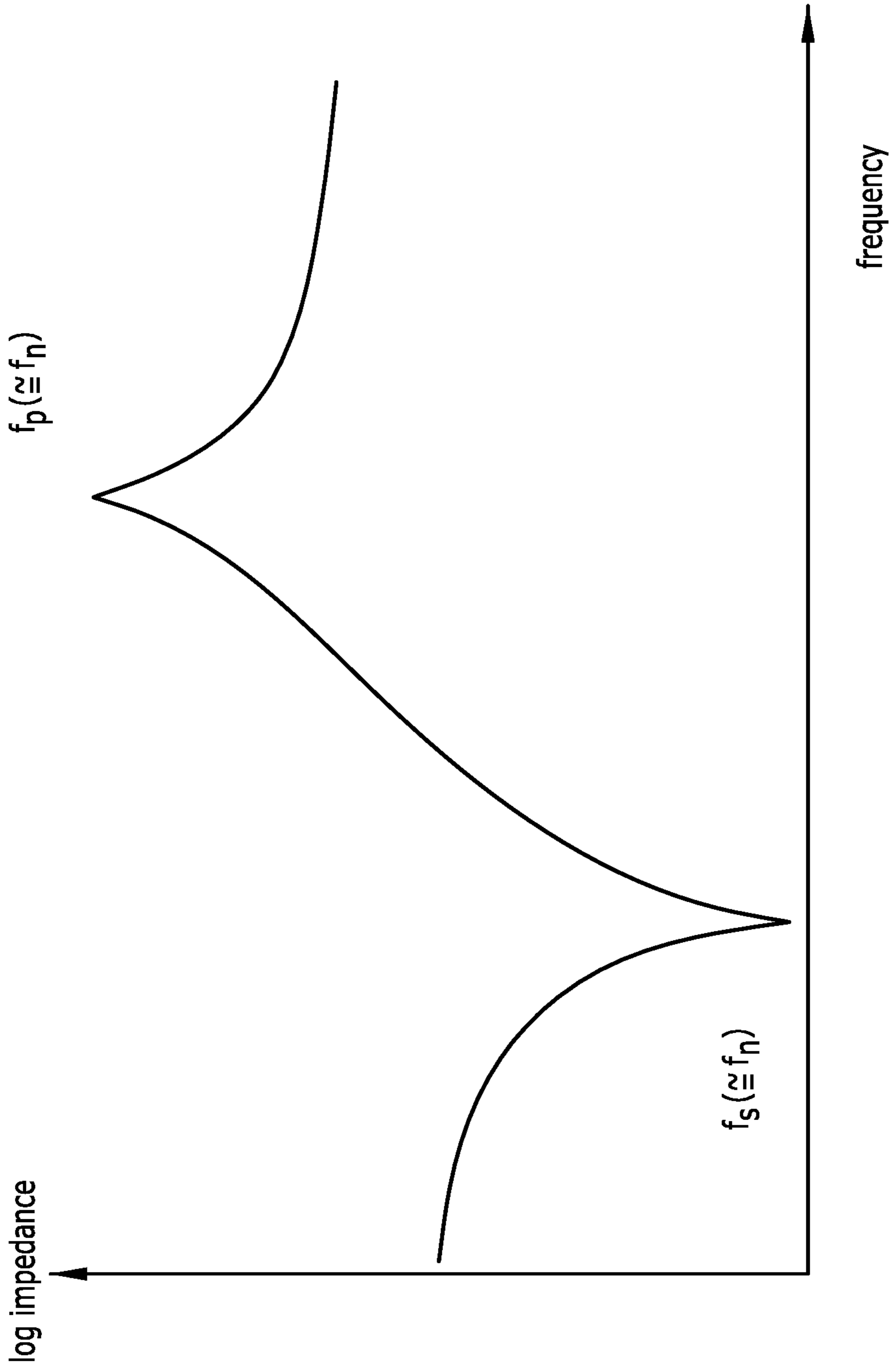


FIG. 6

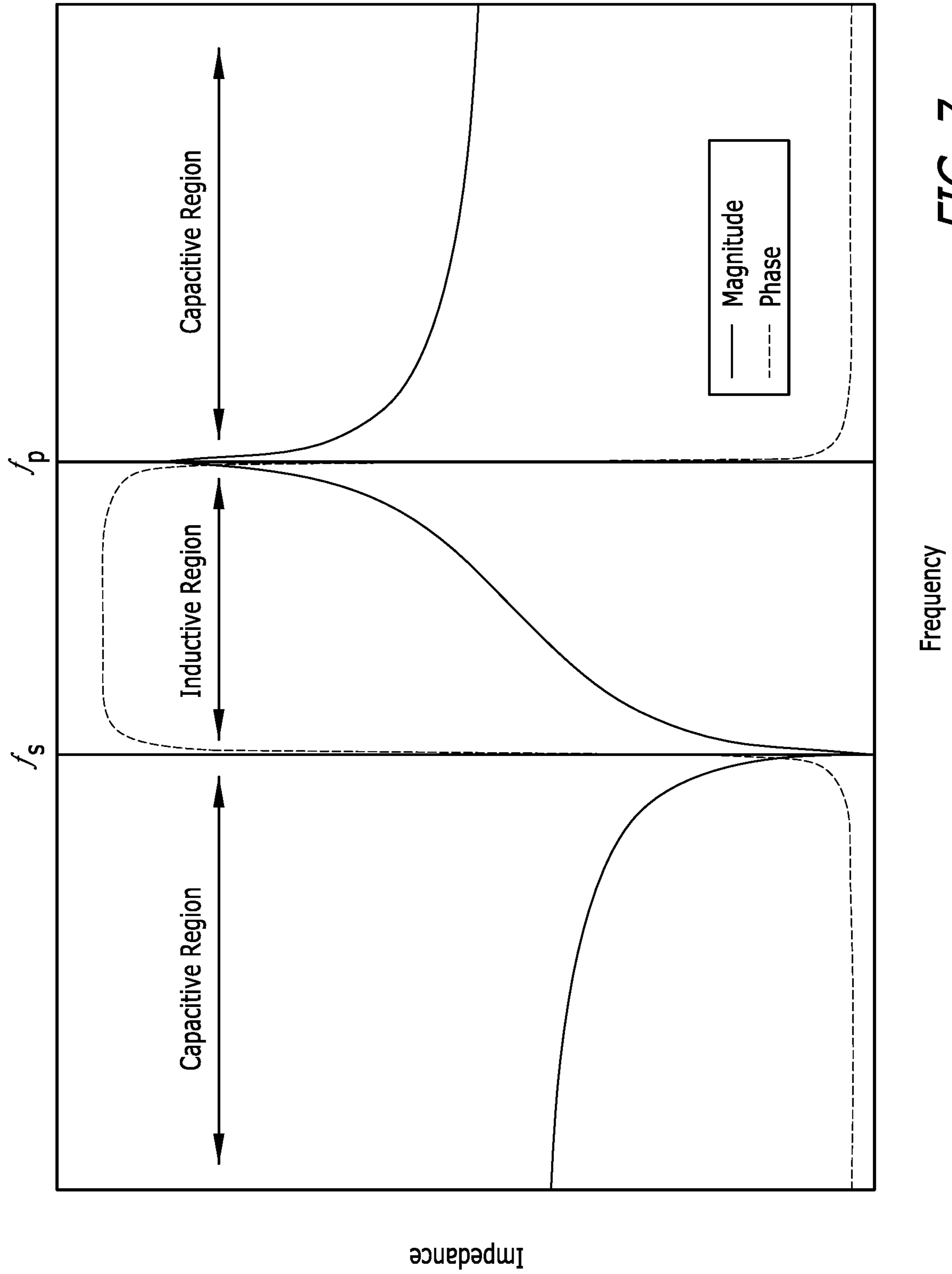


FIG. 7

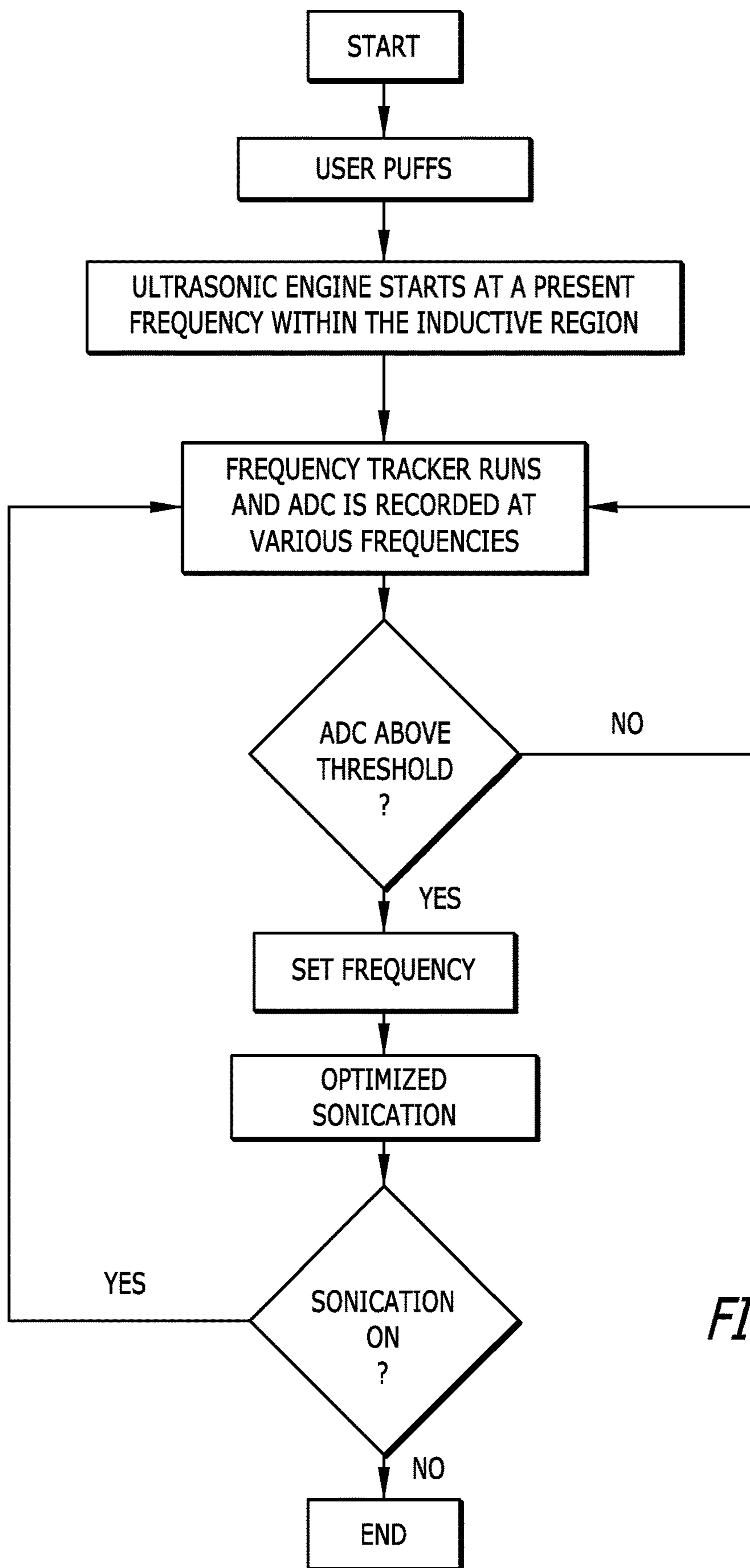
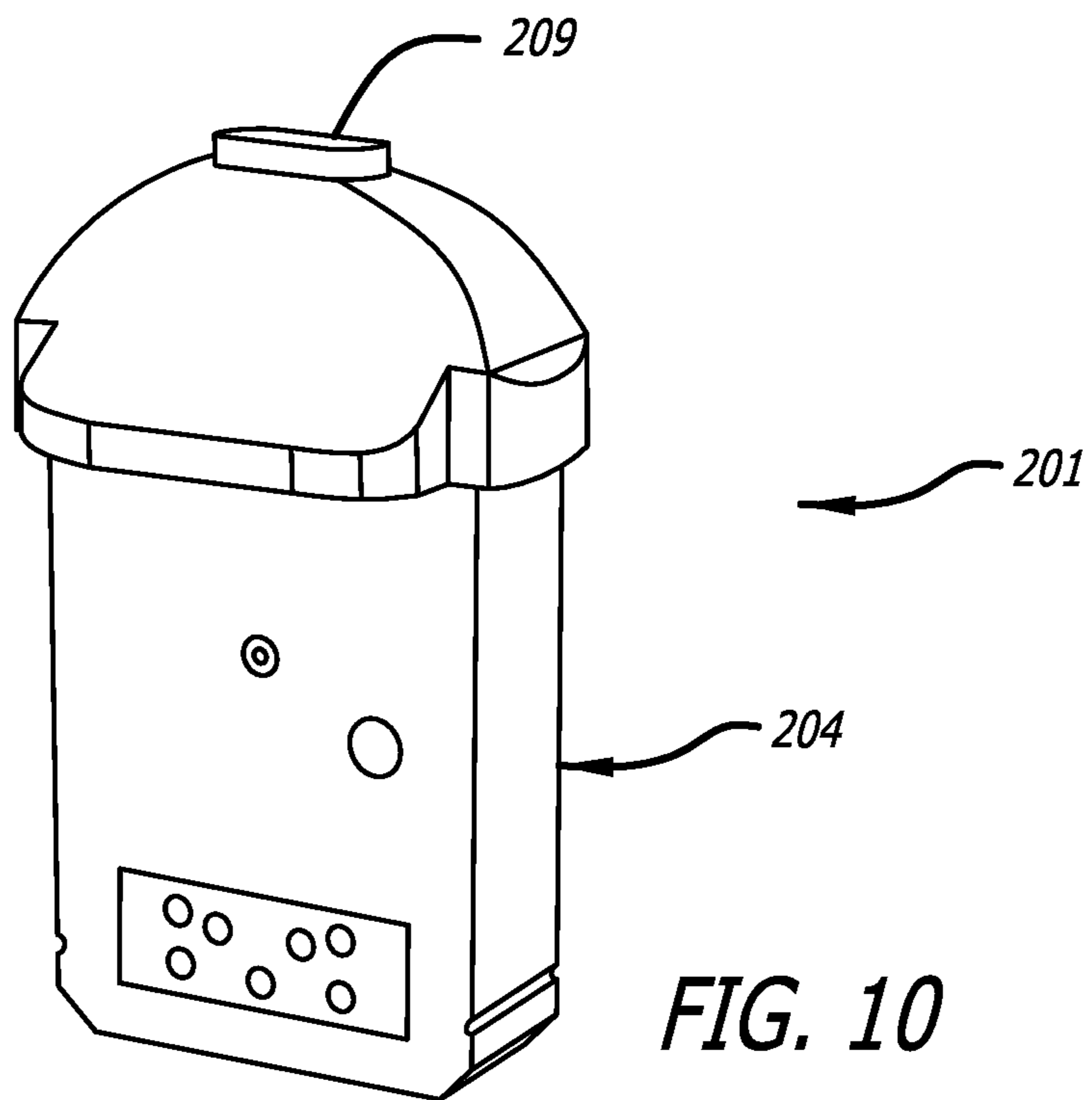
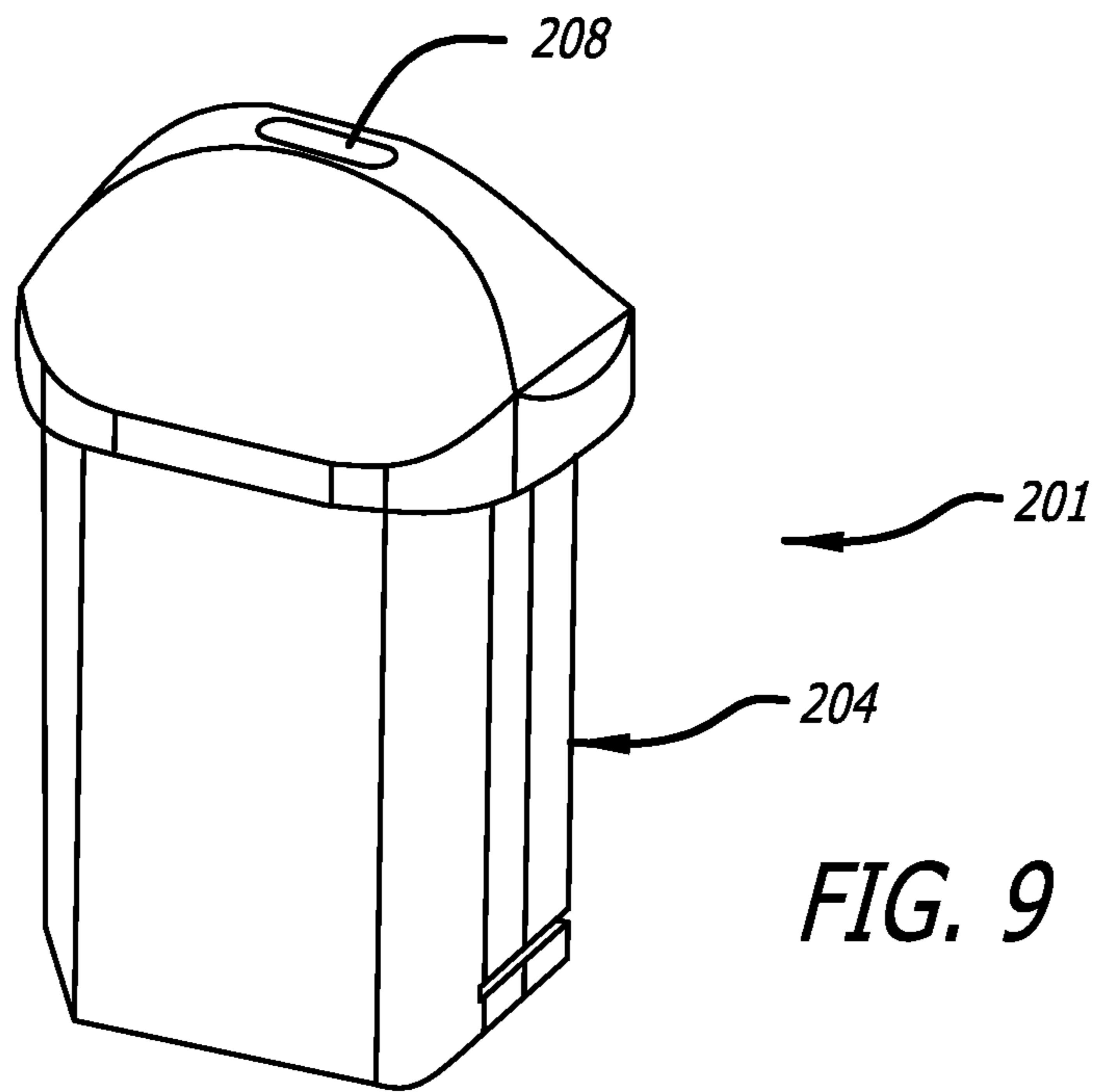


FIG. 8



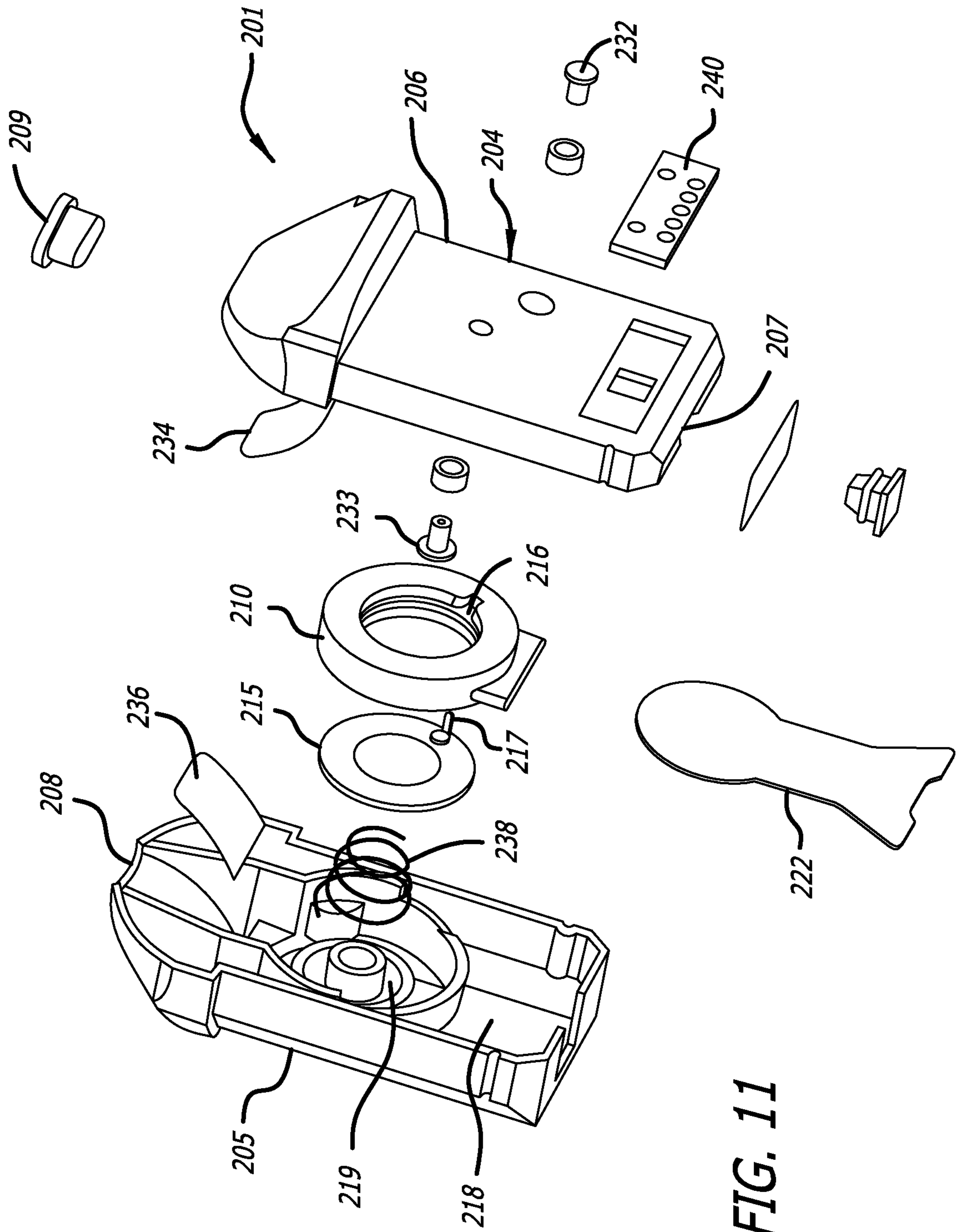
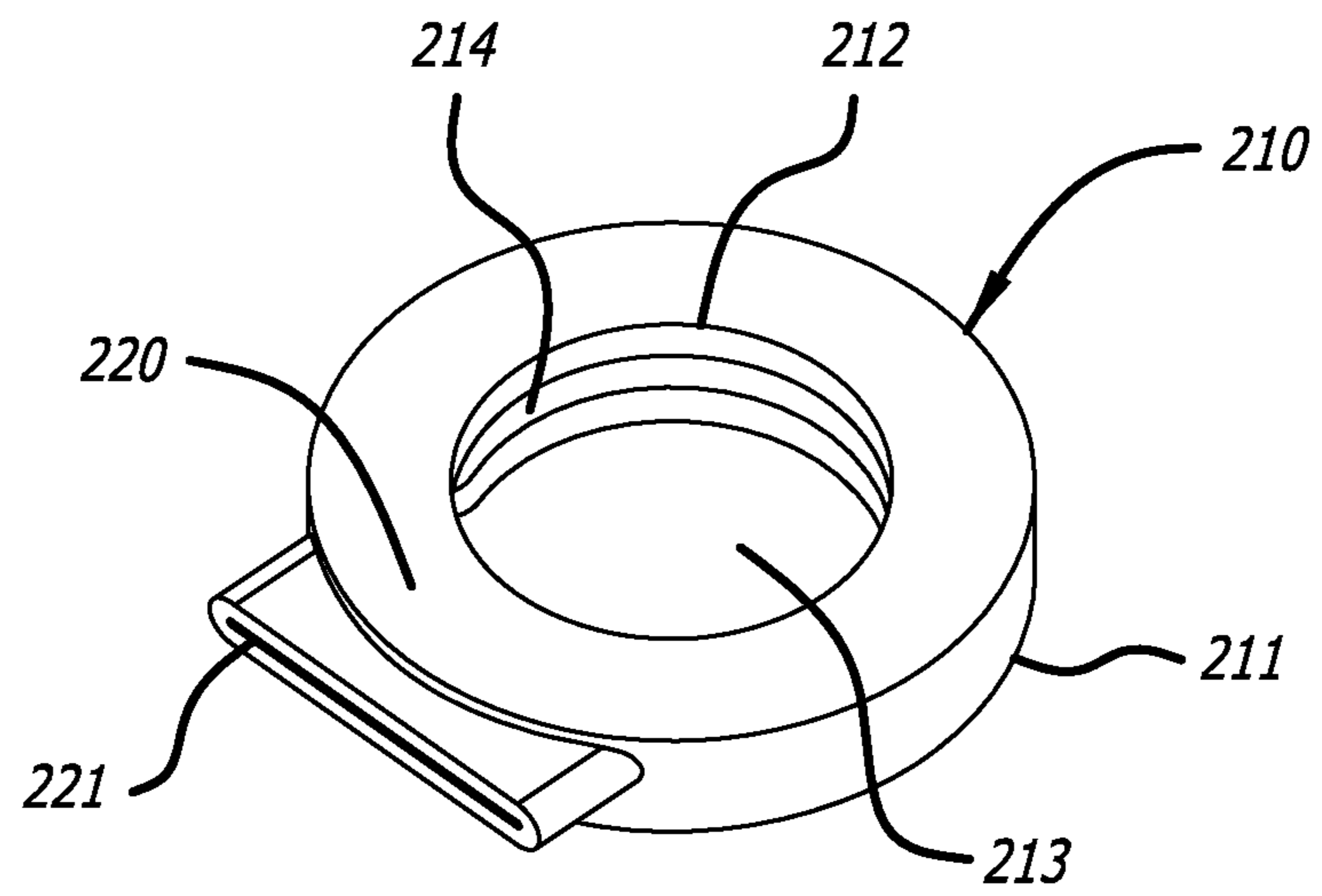
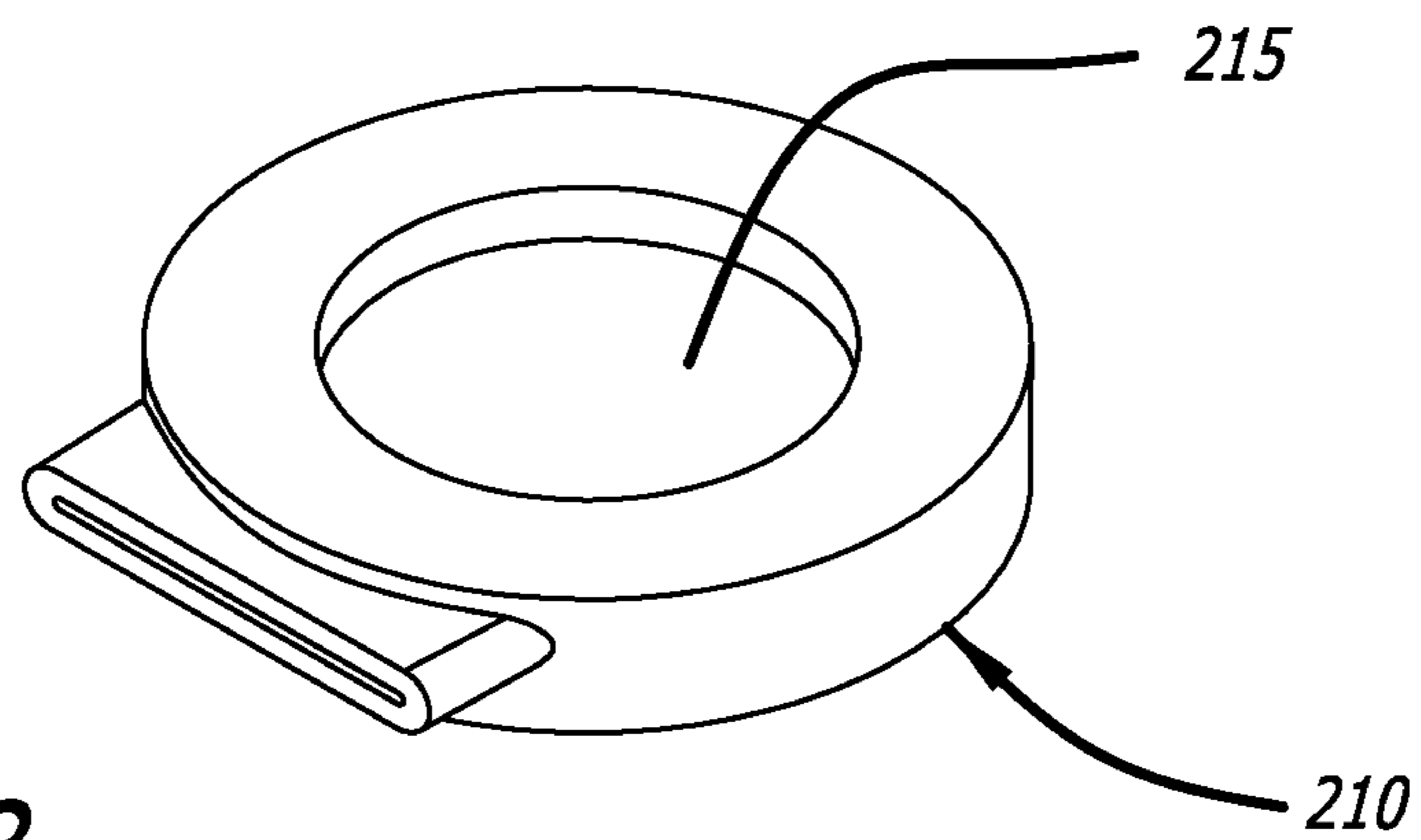


FIG. 11

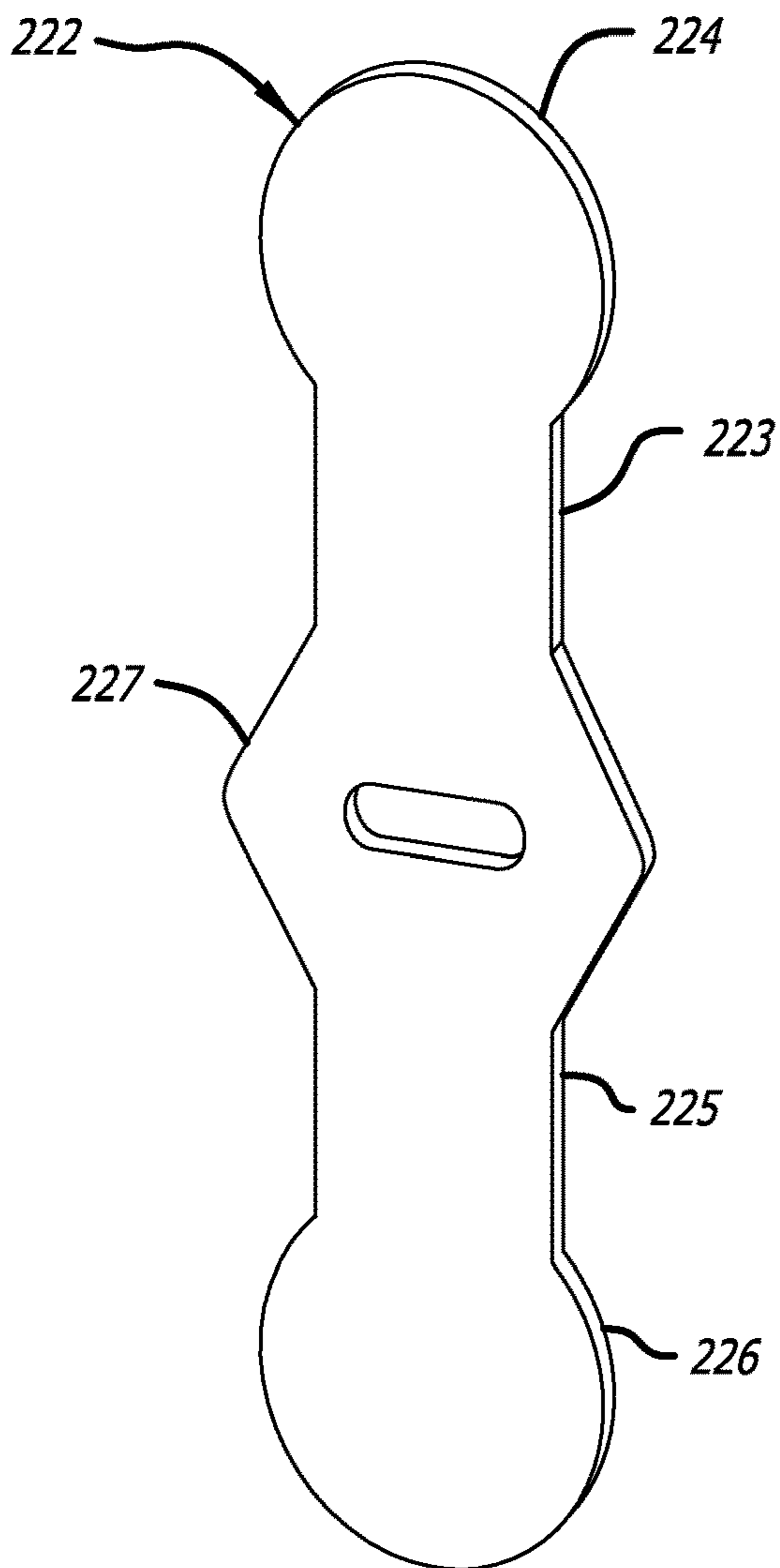


**FIG. 12**

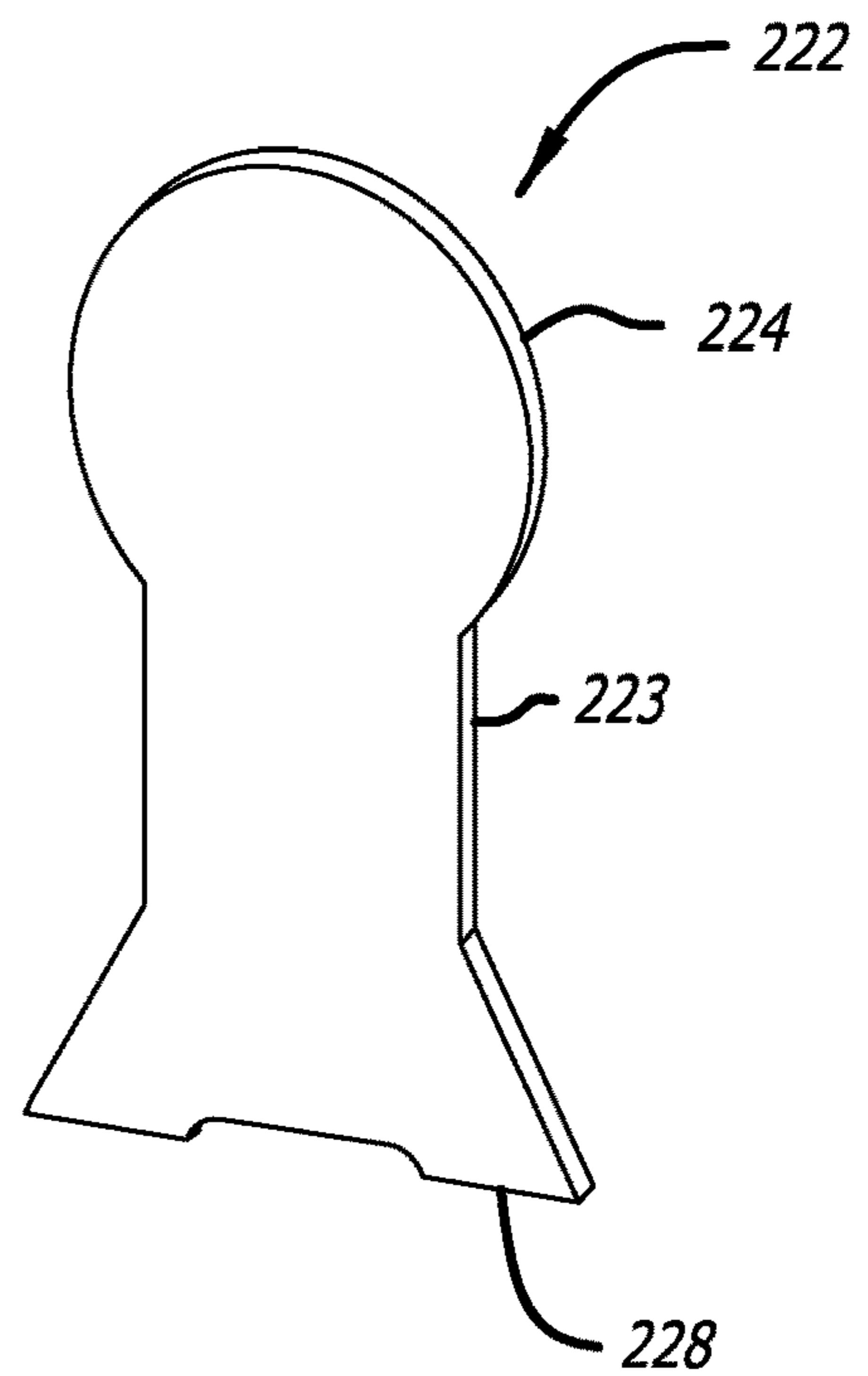


**FIG. 13**

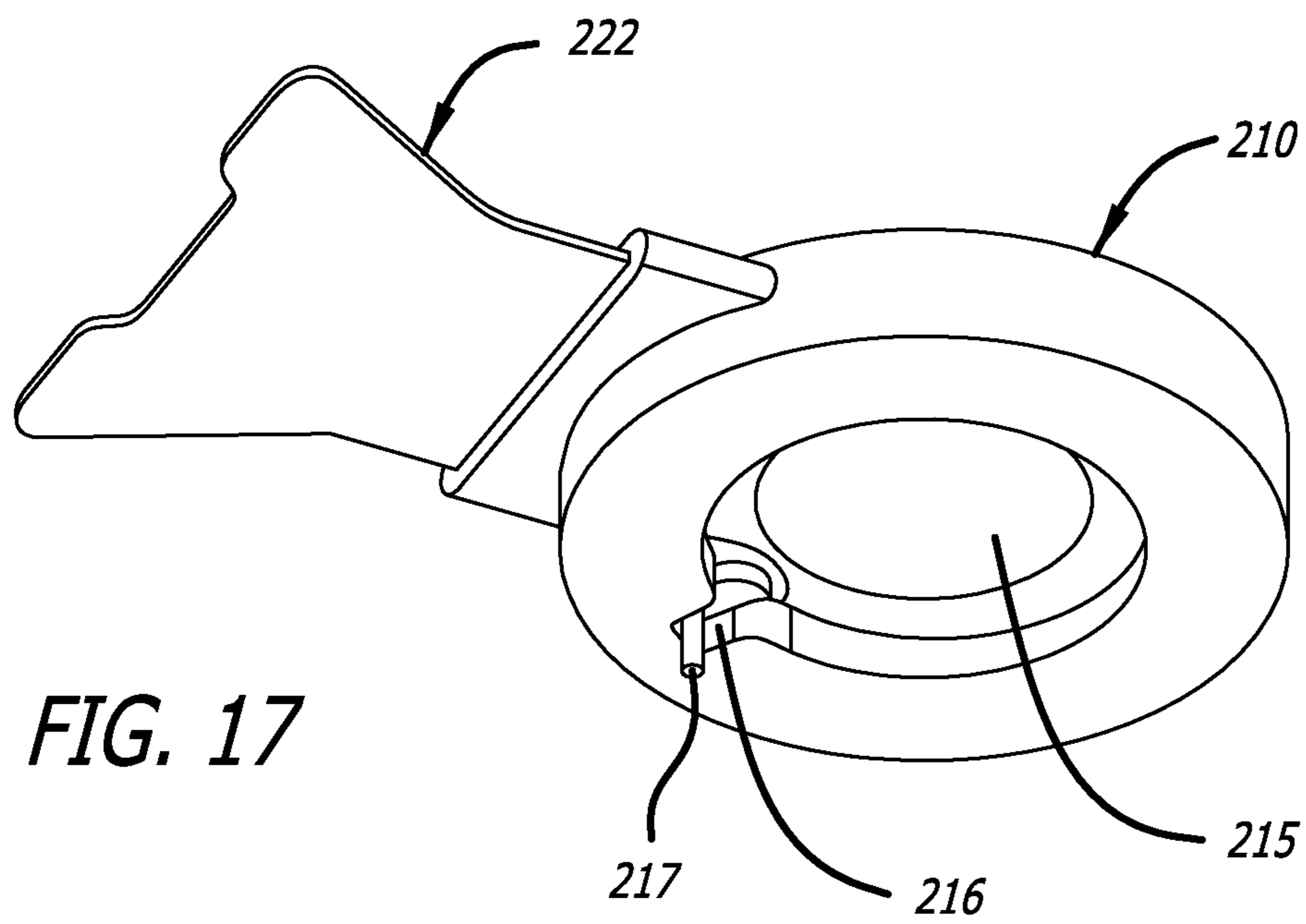
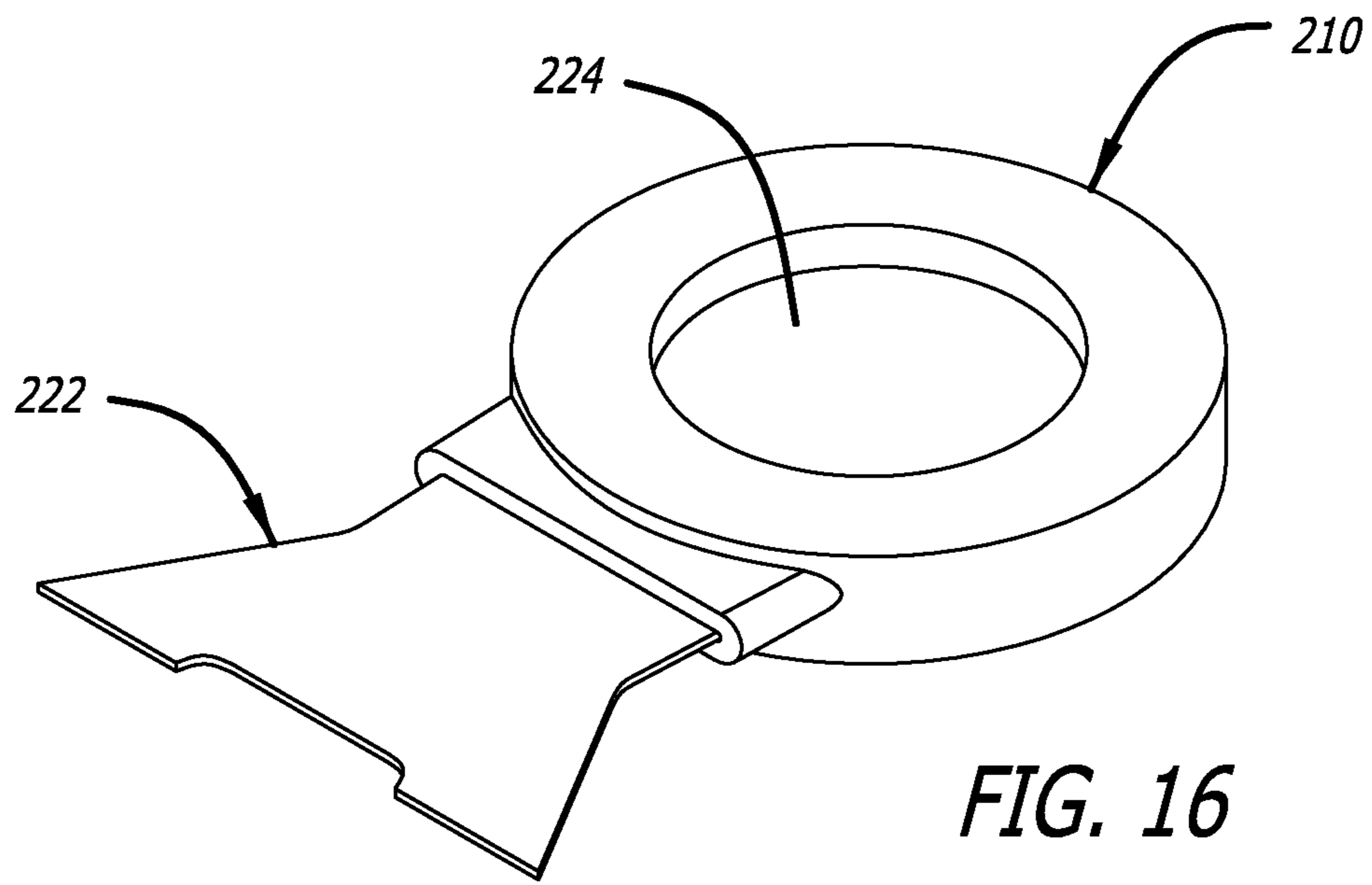


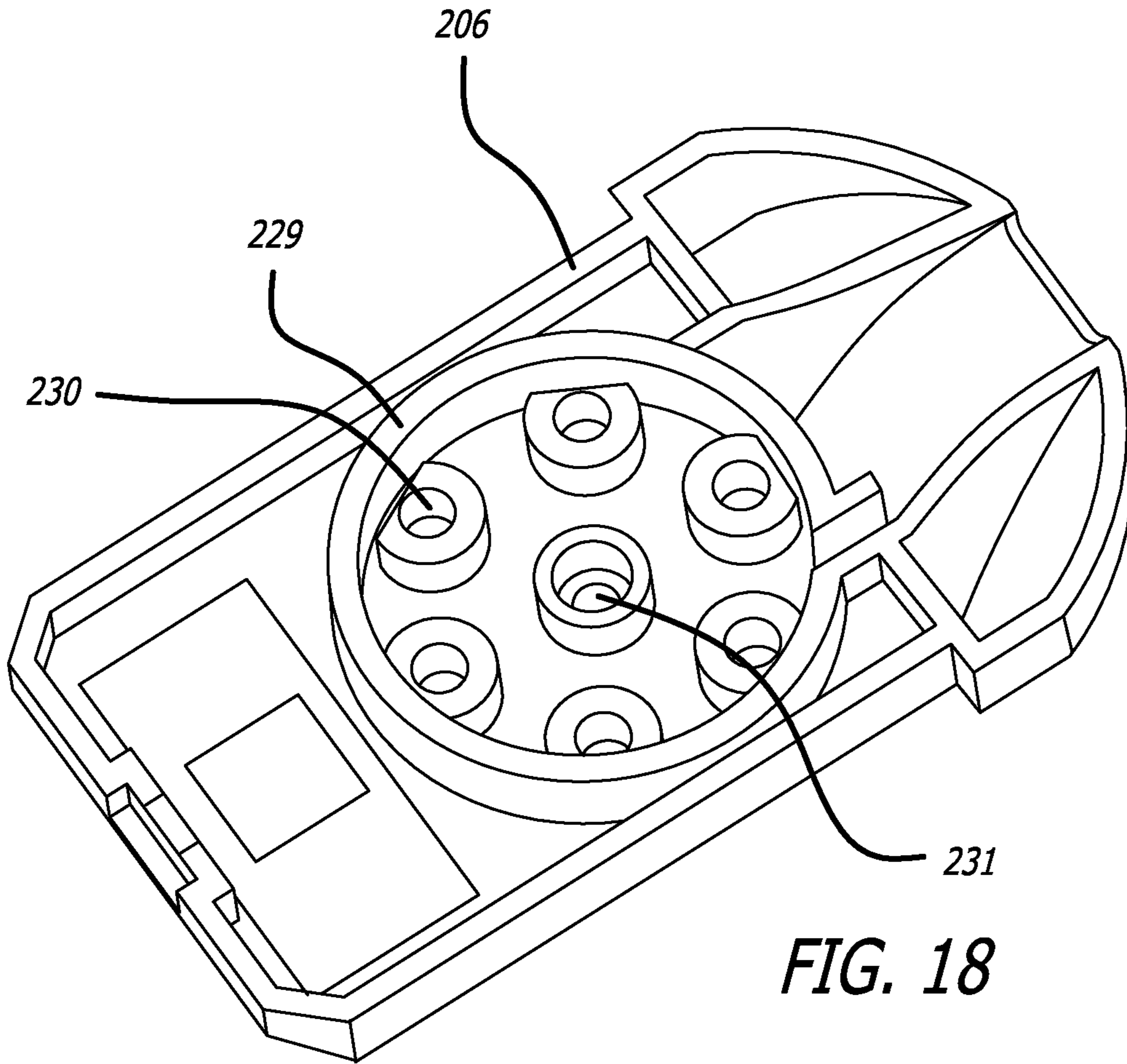


**FIG. 14**

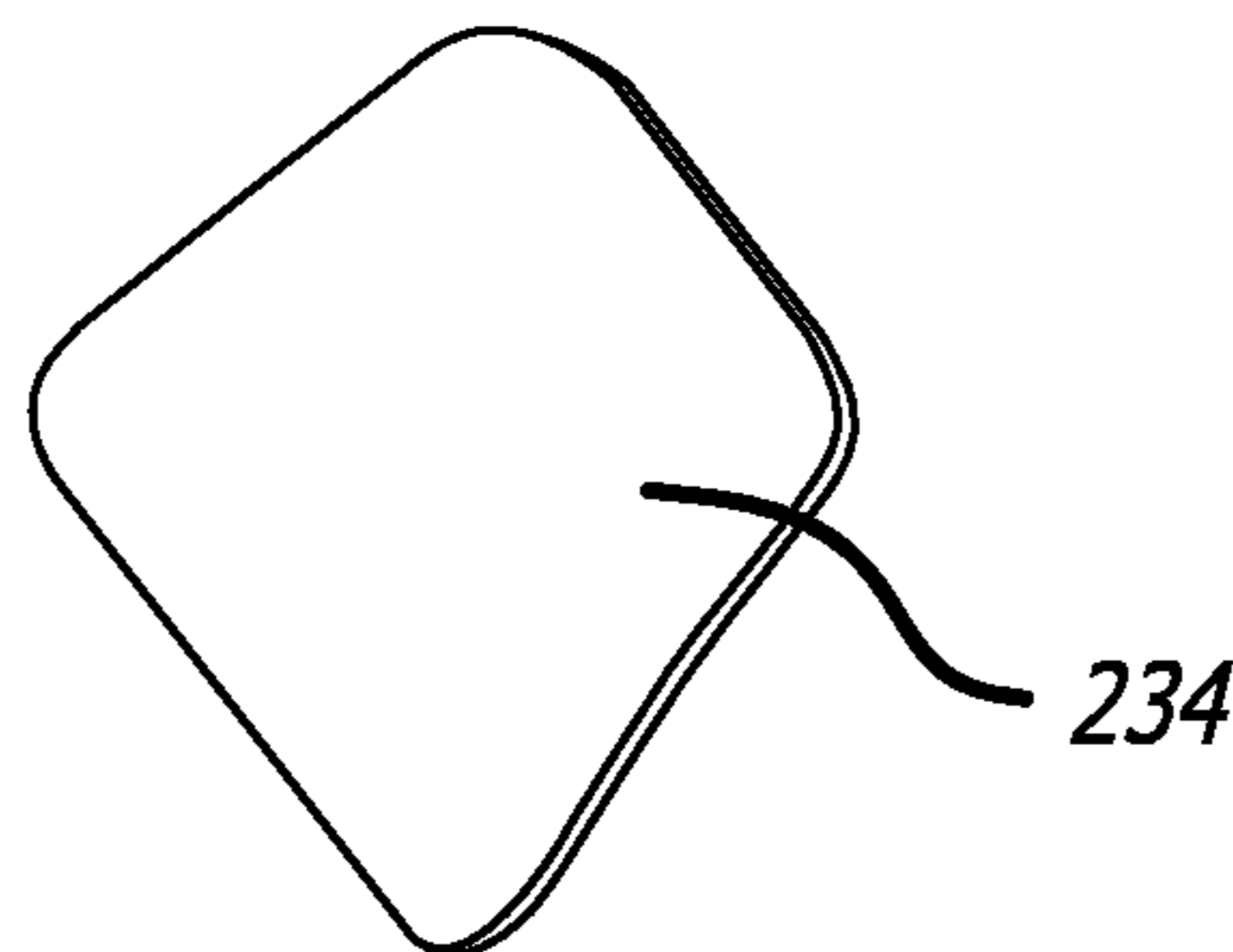


**FIG. 15**

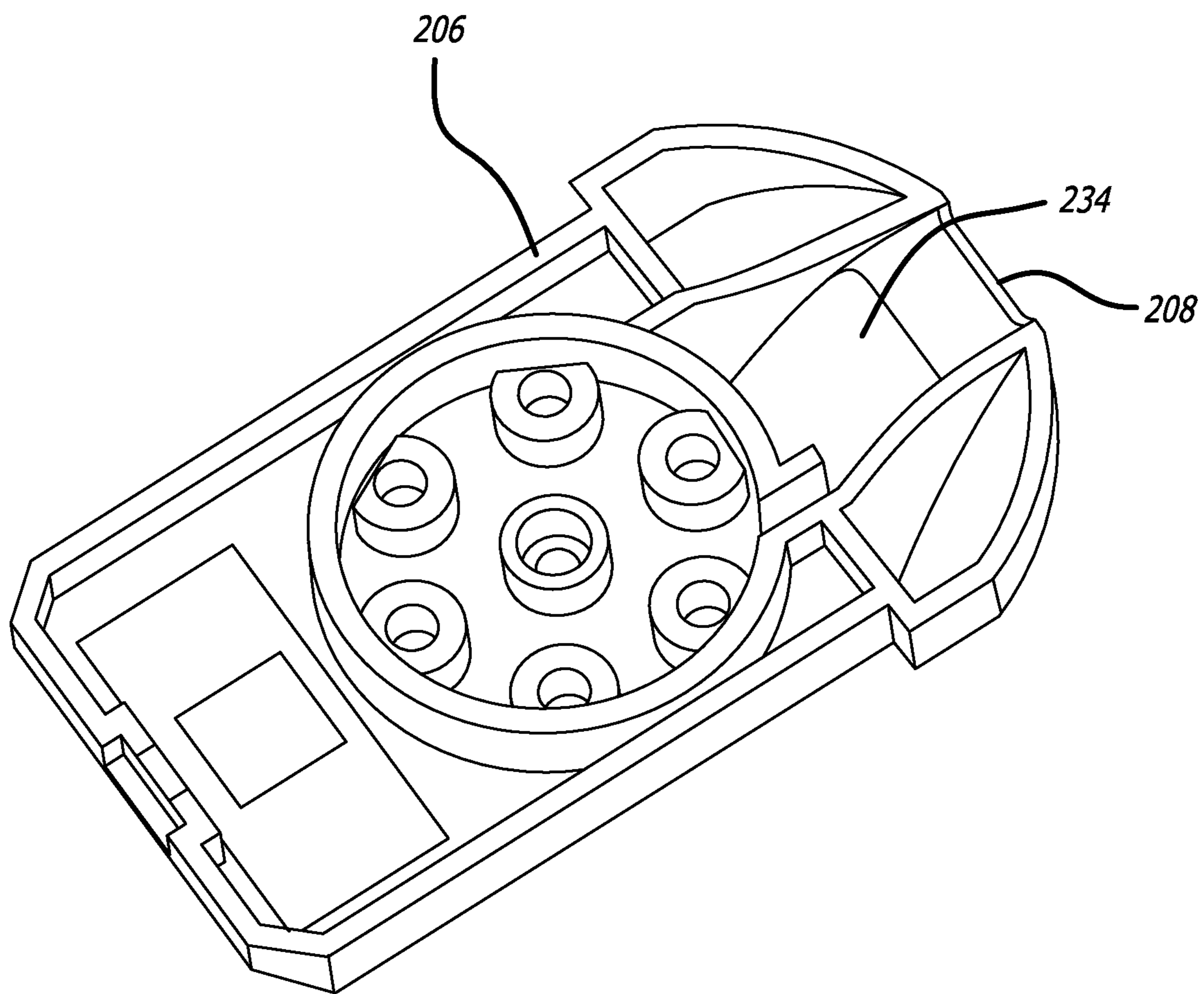




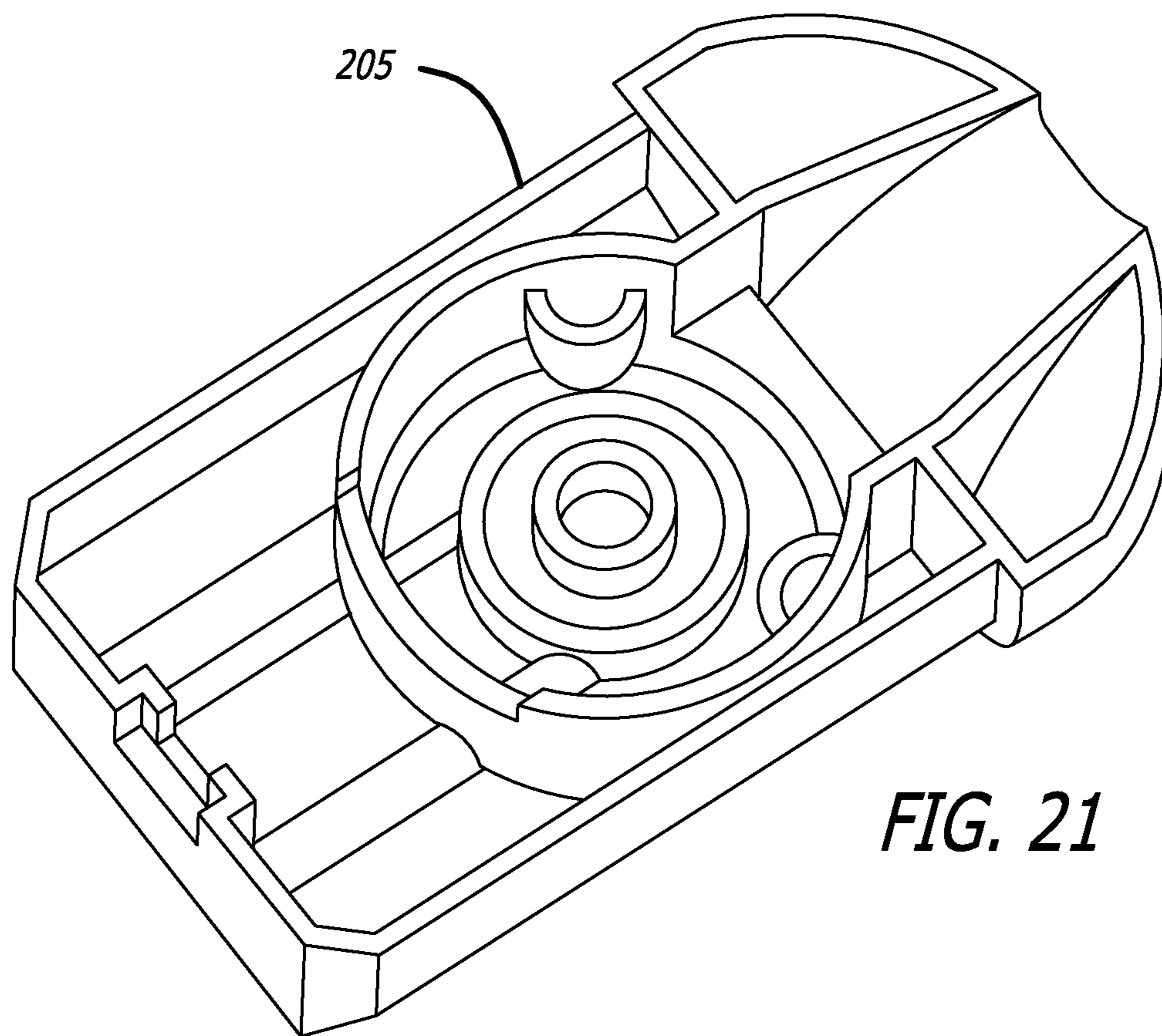
**FIG. 18**



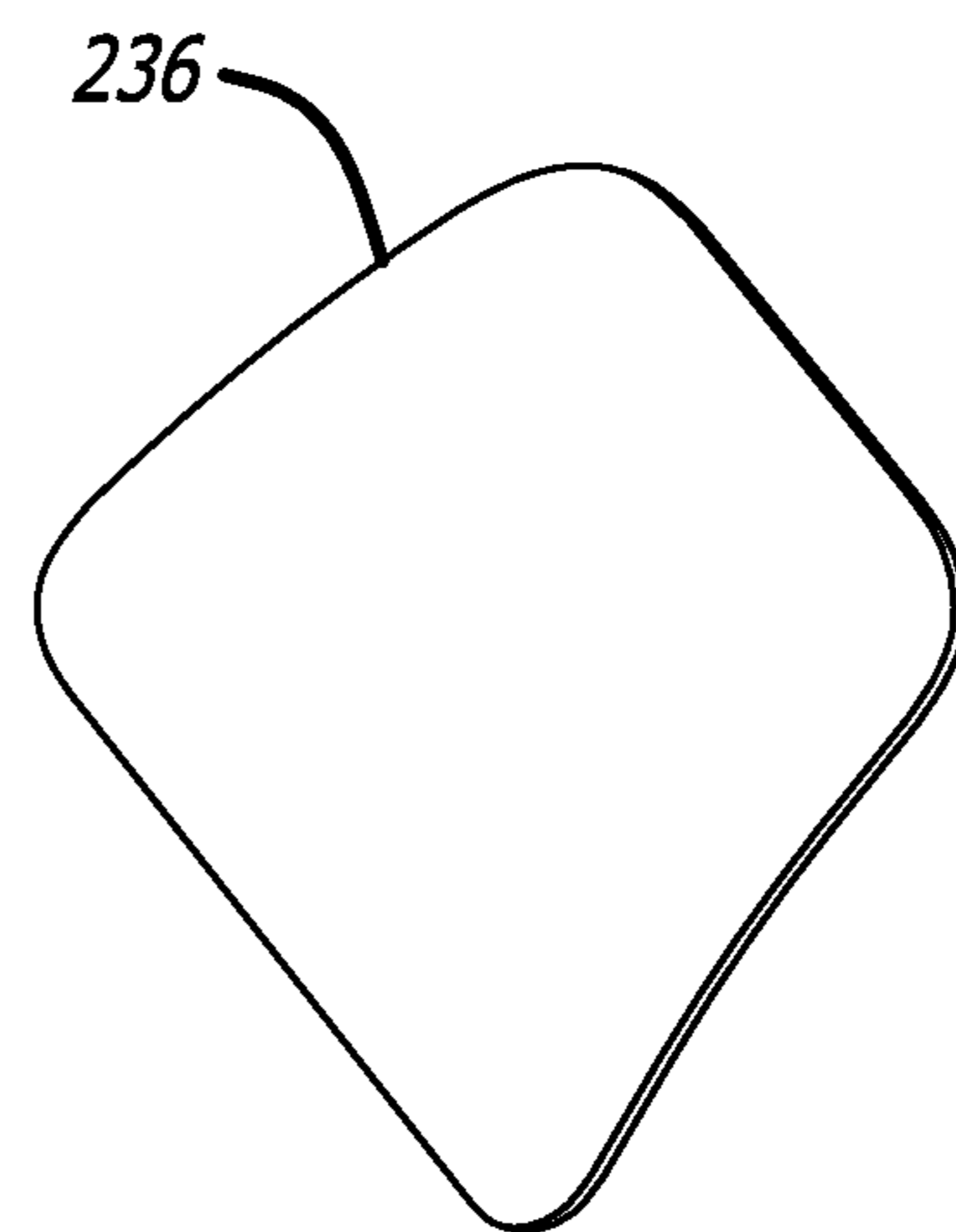
**FIG. 19**



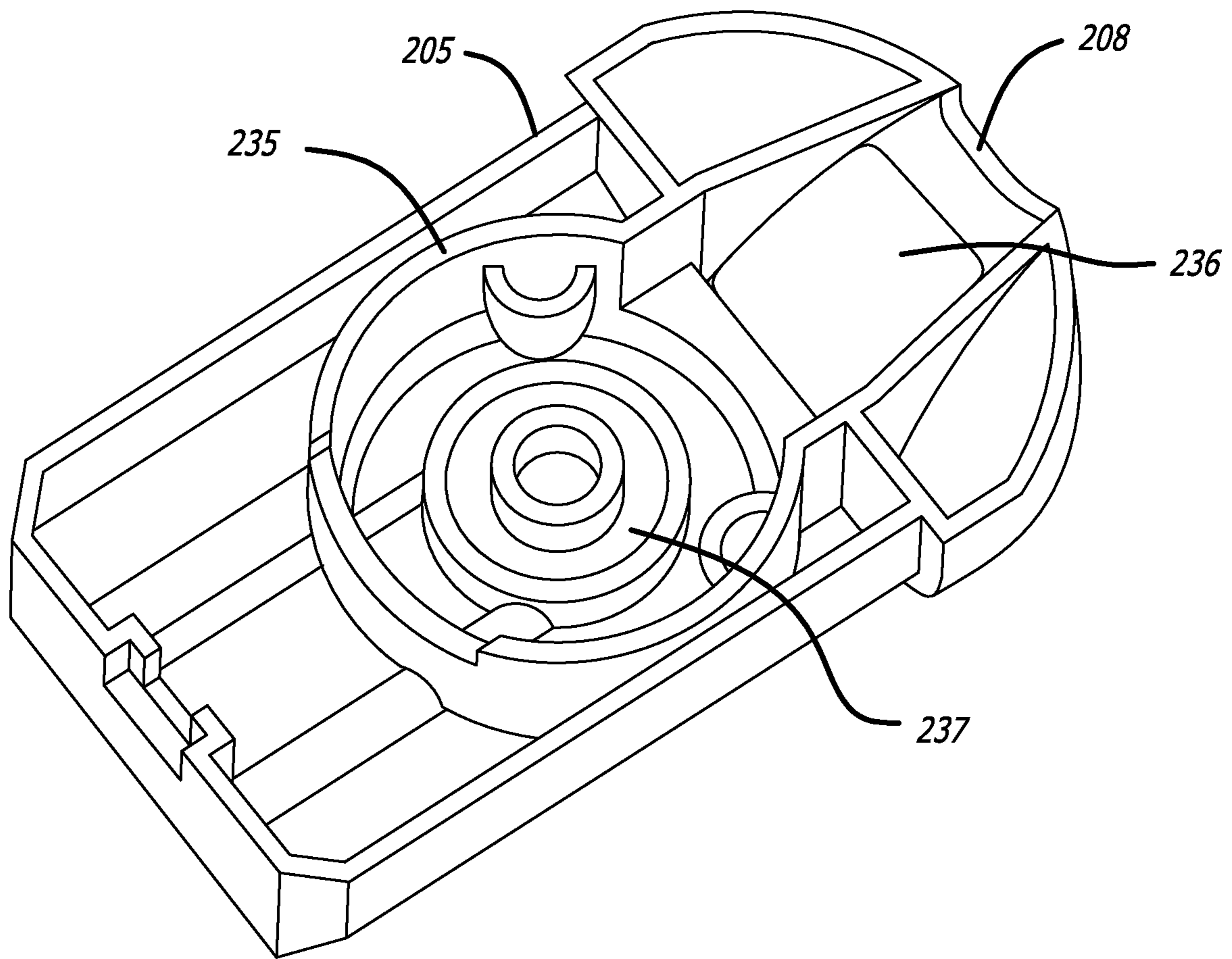
**FIG. 20**



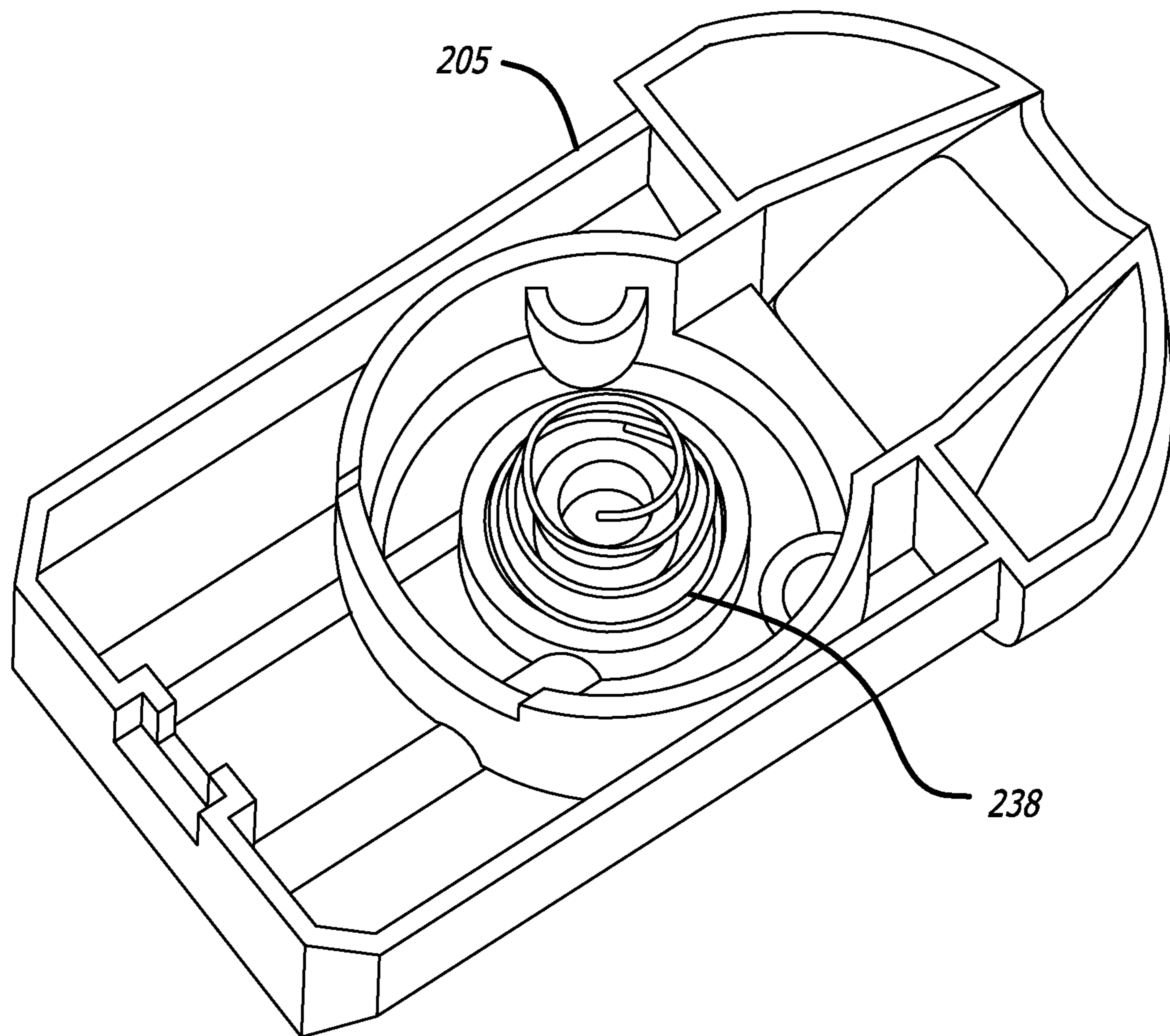
**FIG. 21**



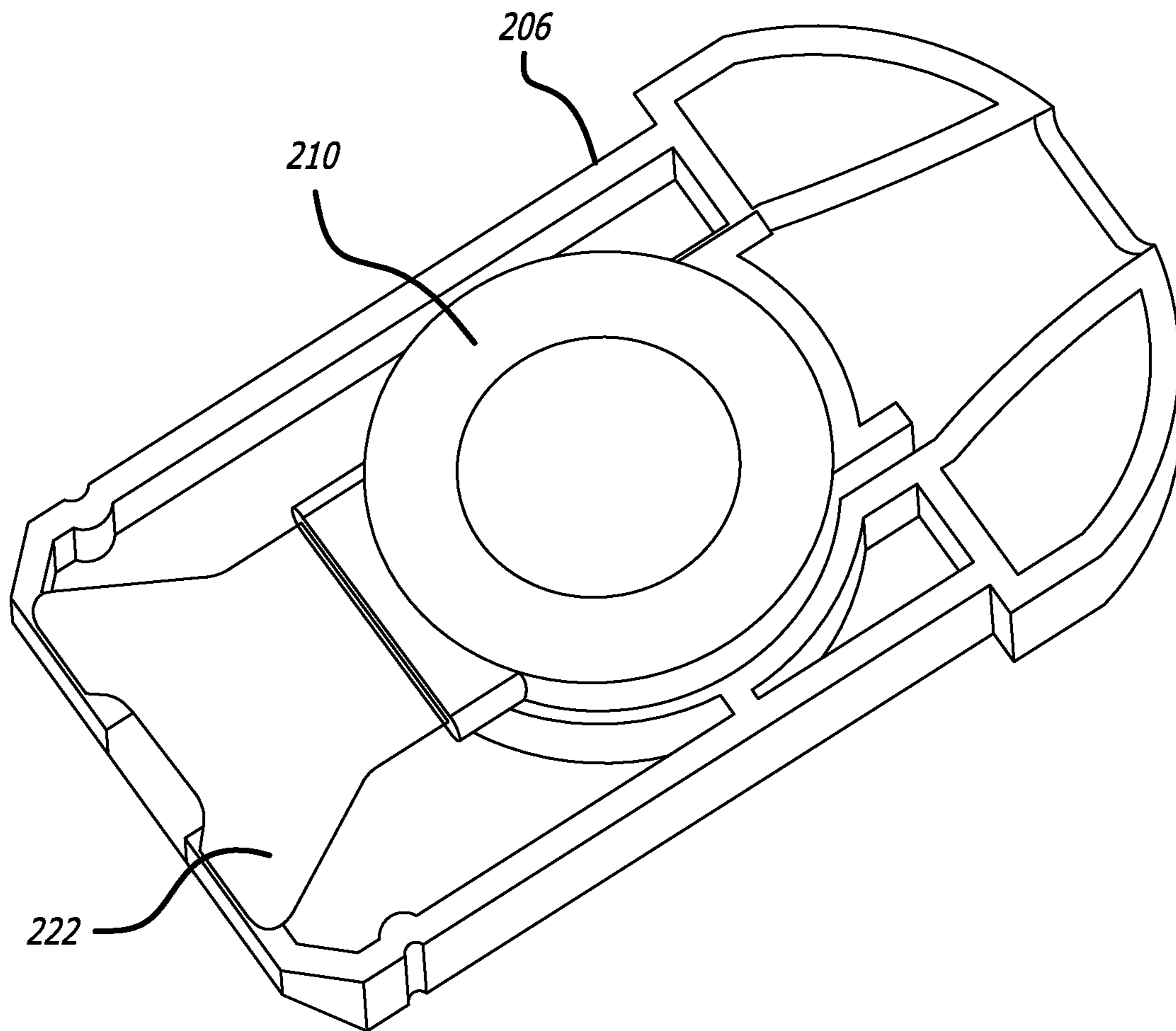
**FIG. 22**



**FIG. 23**



**FIG. 24**



**FIG. 25**



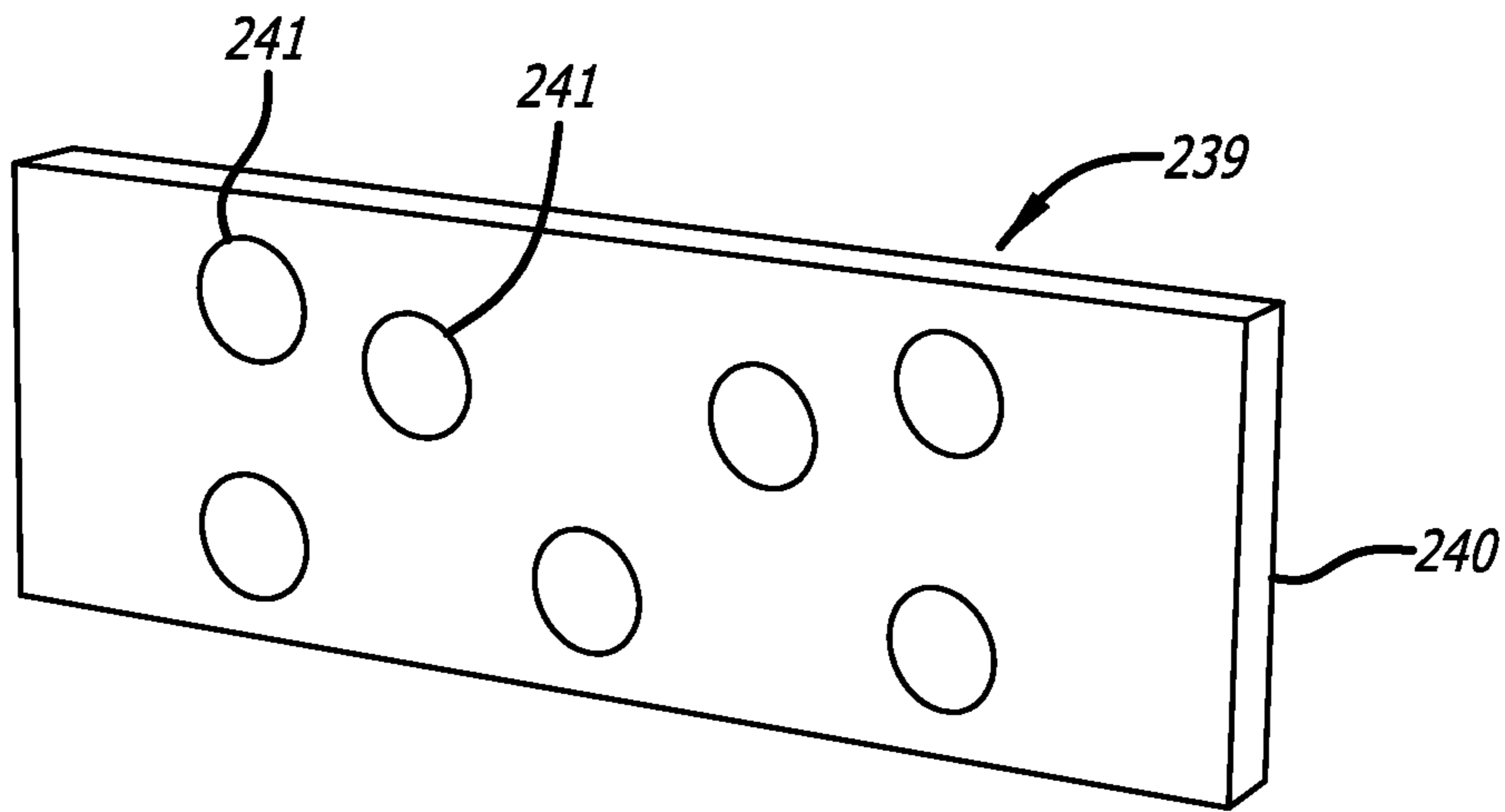


FIG. 26

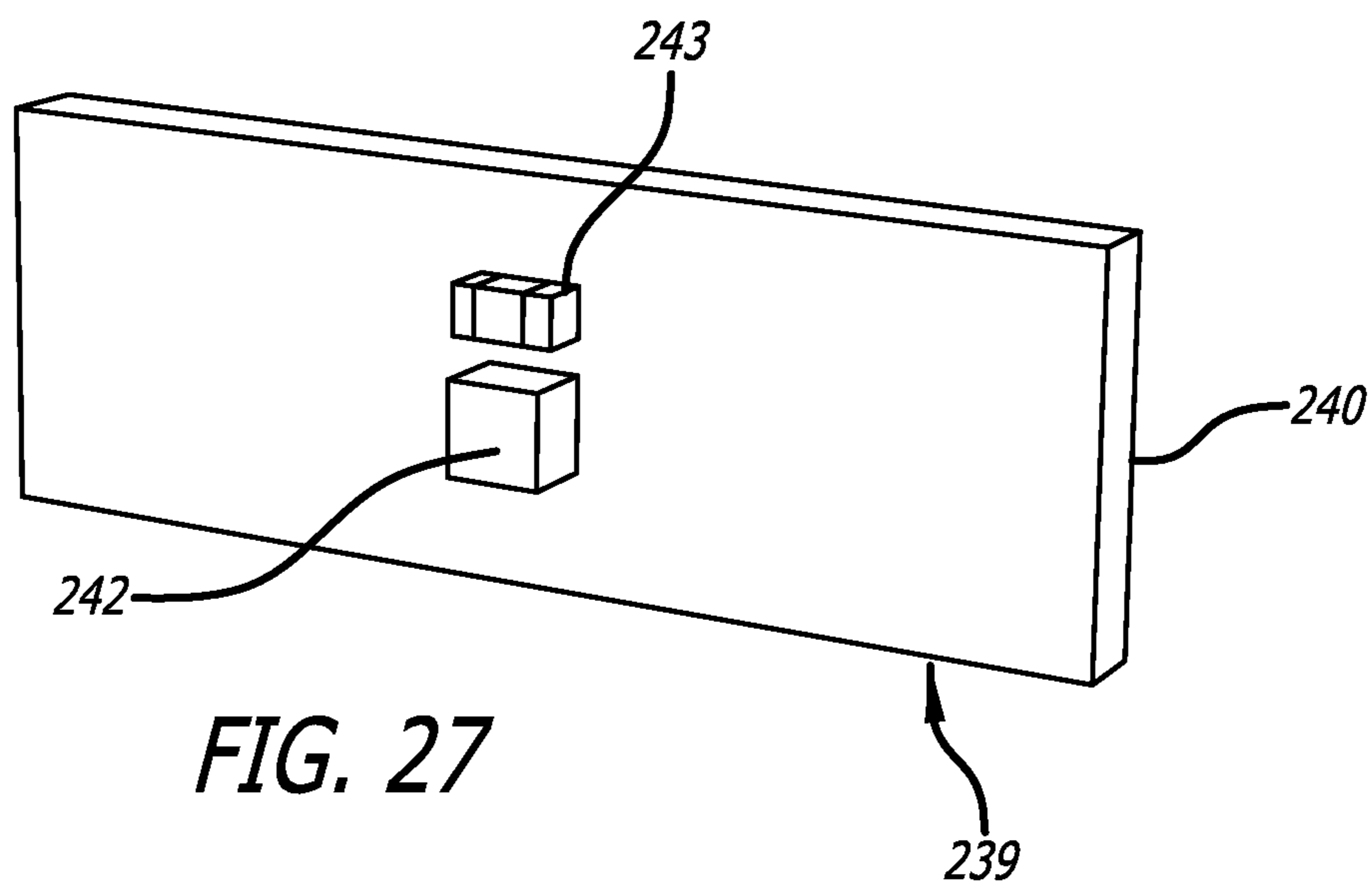


FIG. 27

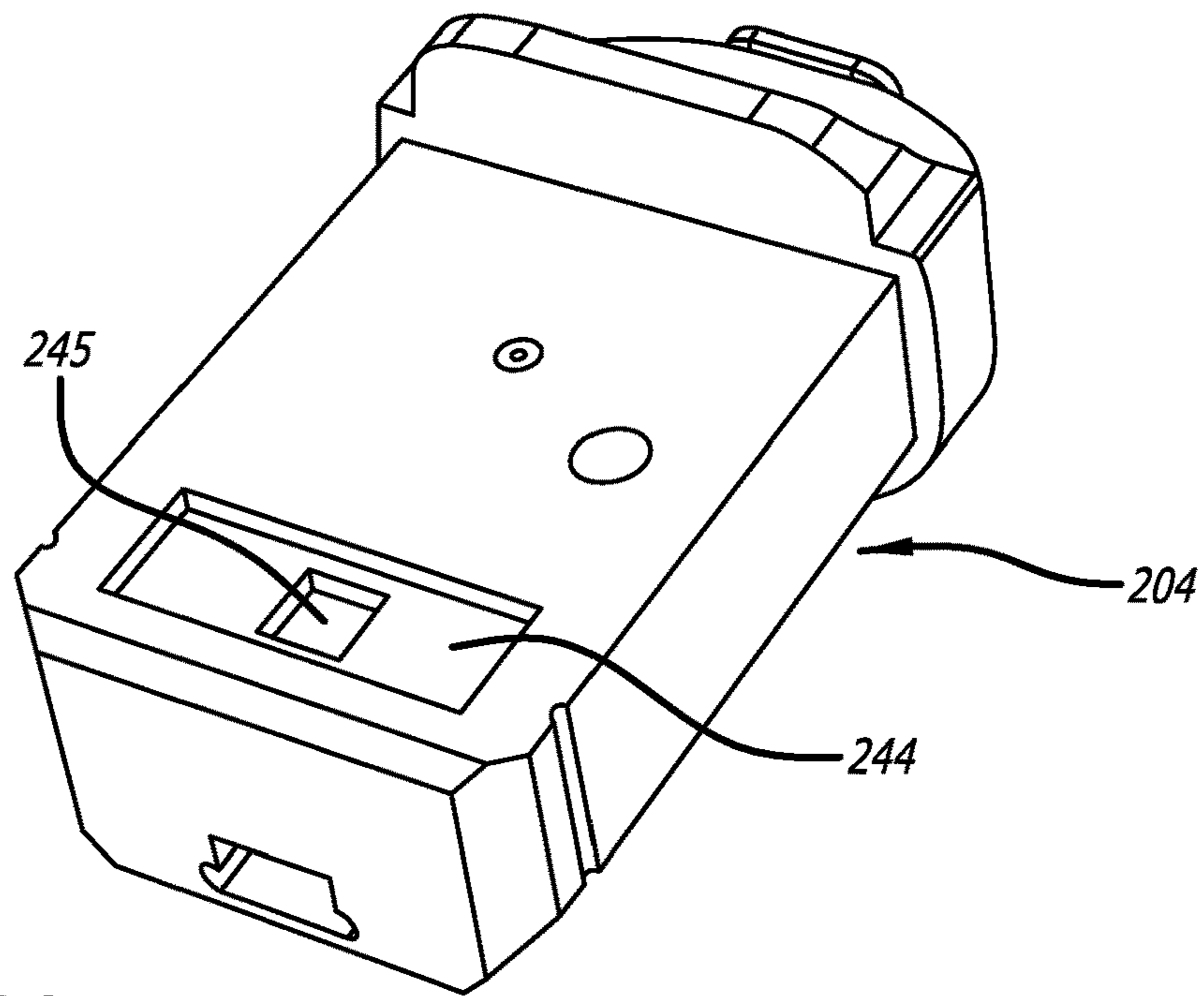


FIG. 28

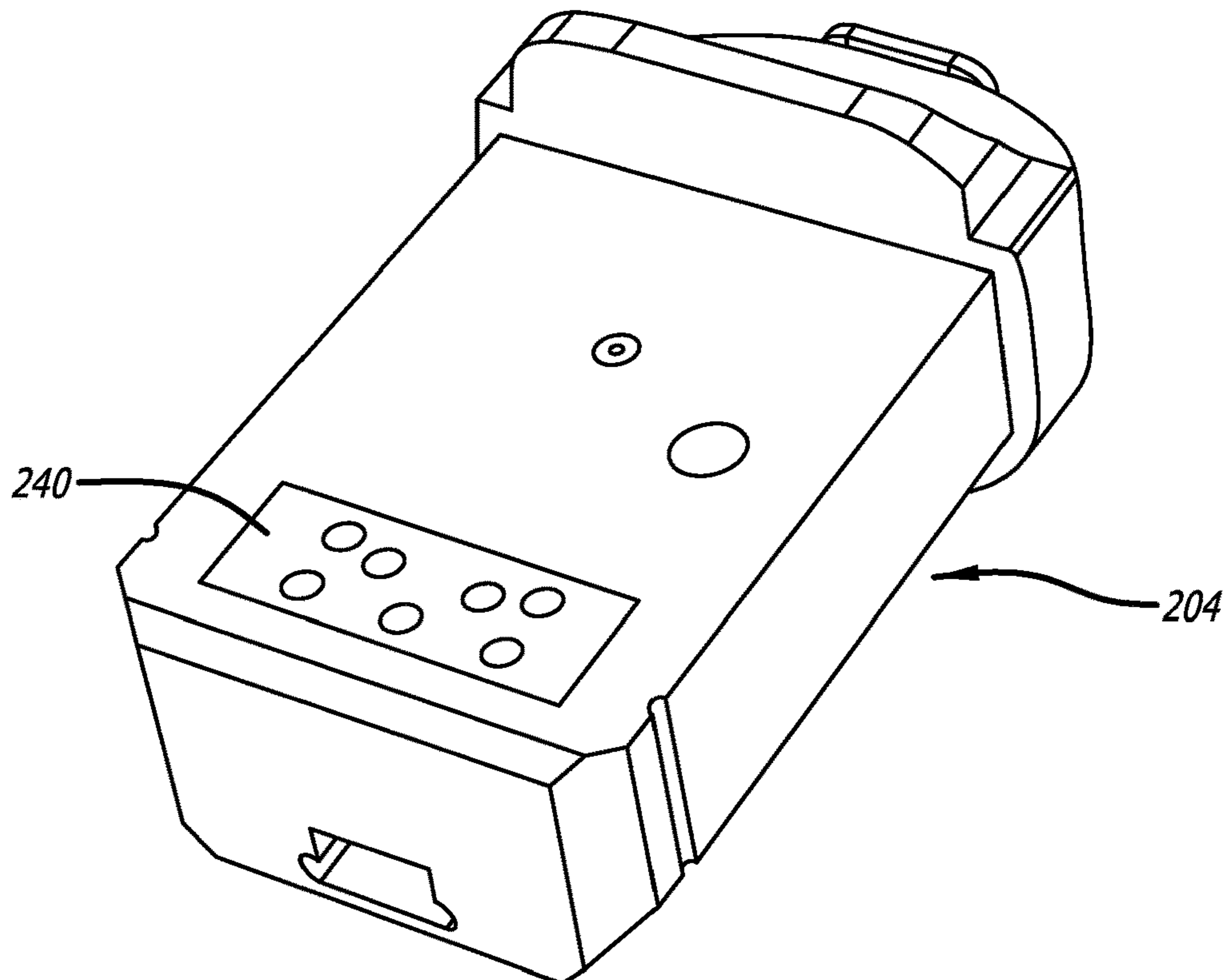
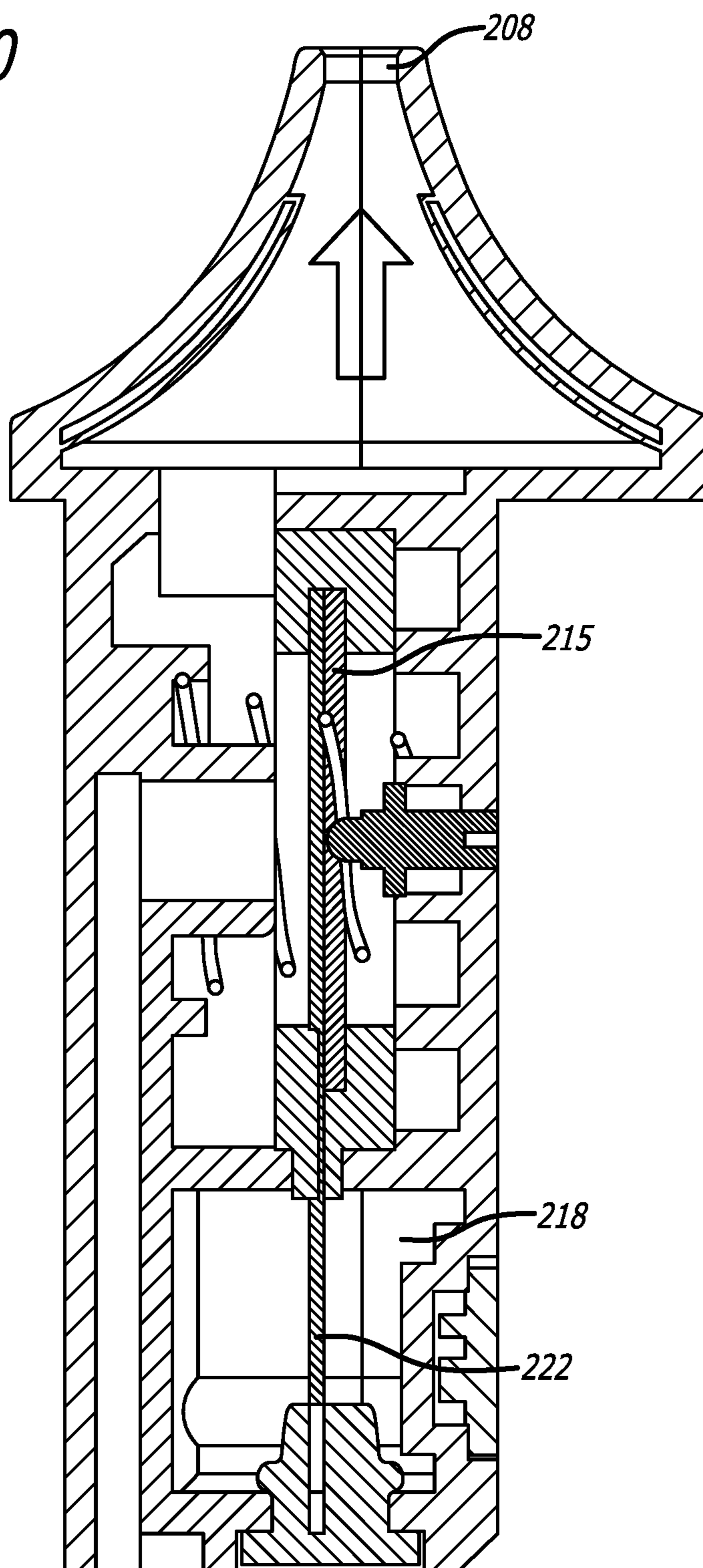
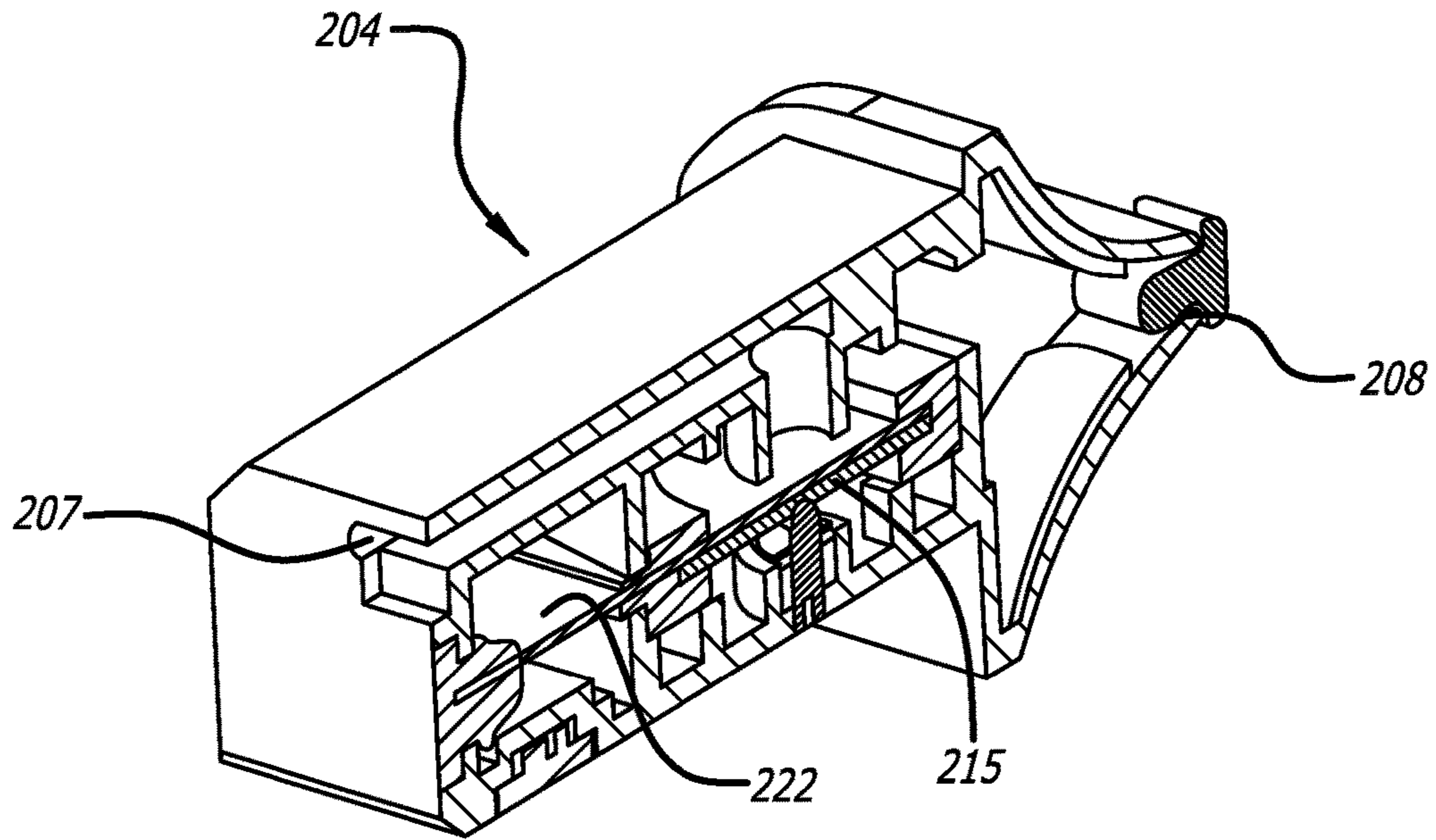


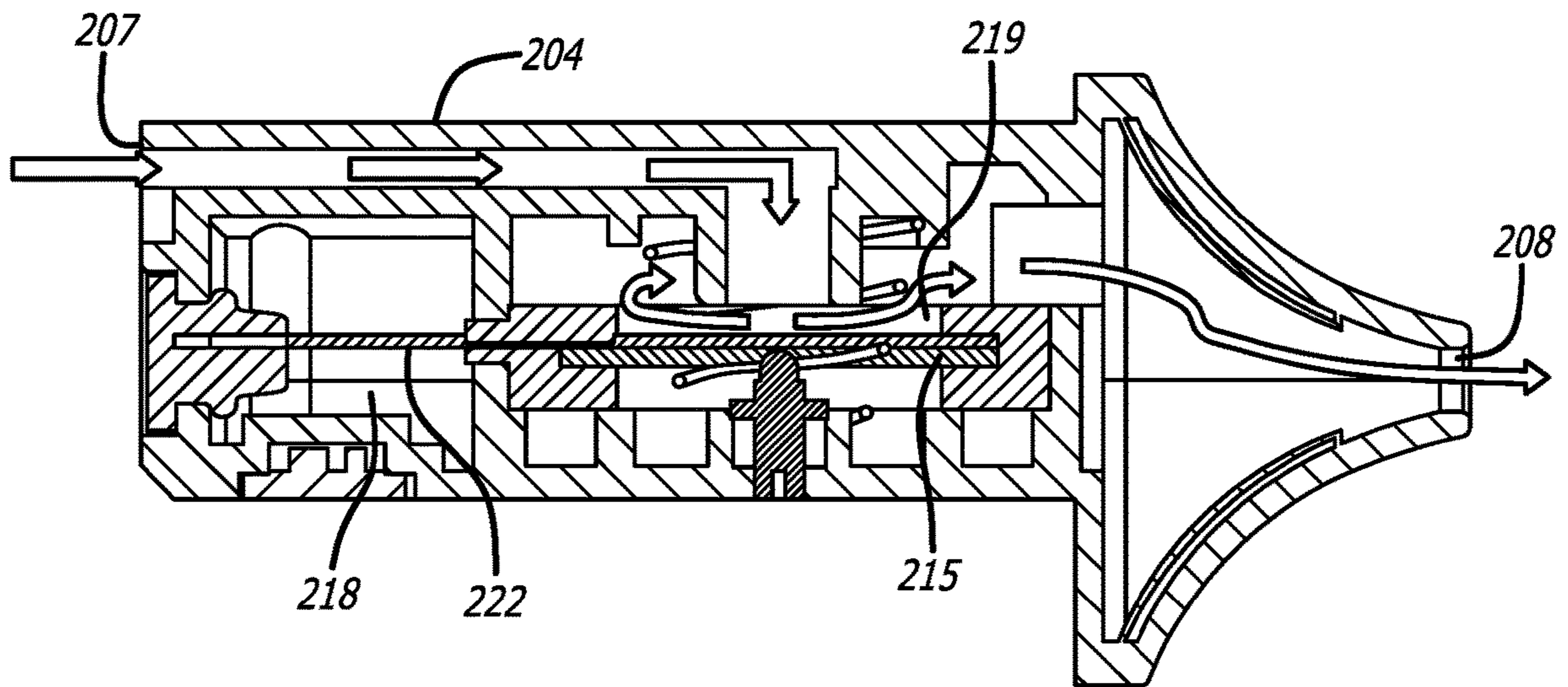
FIG. 29

FIG. 30





**FIG. 31**



**FIG. 32**

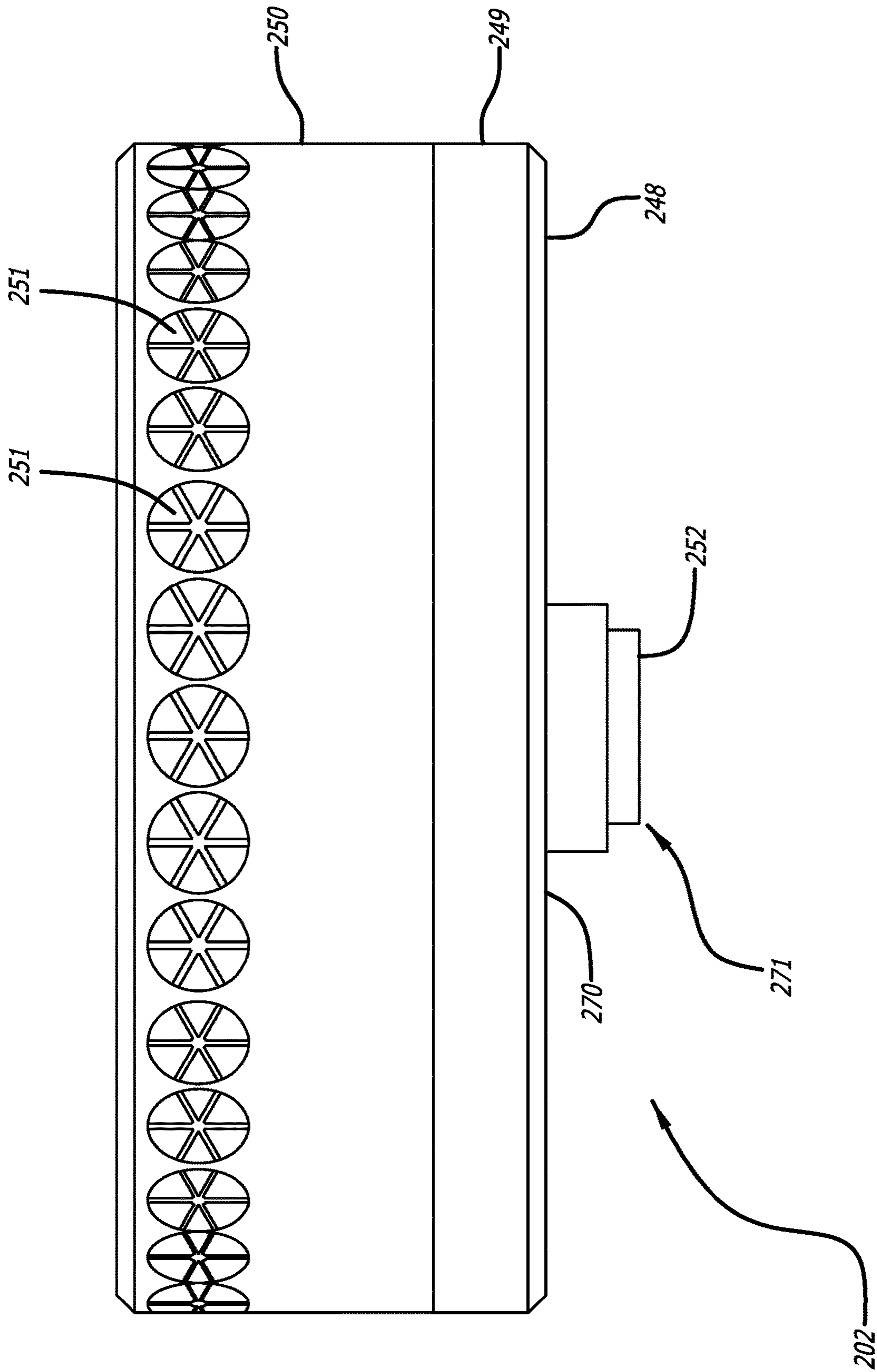
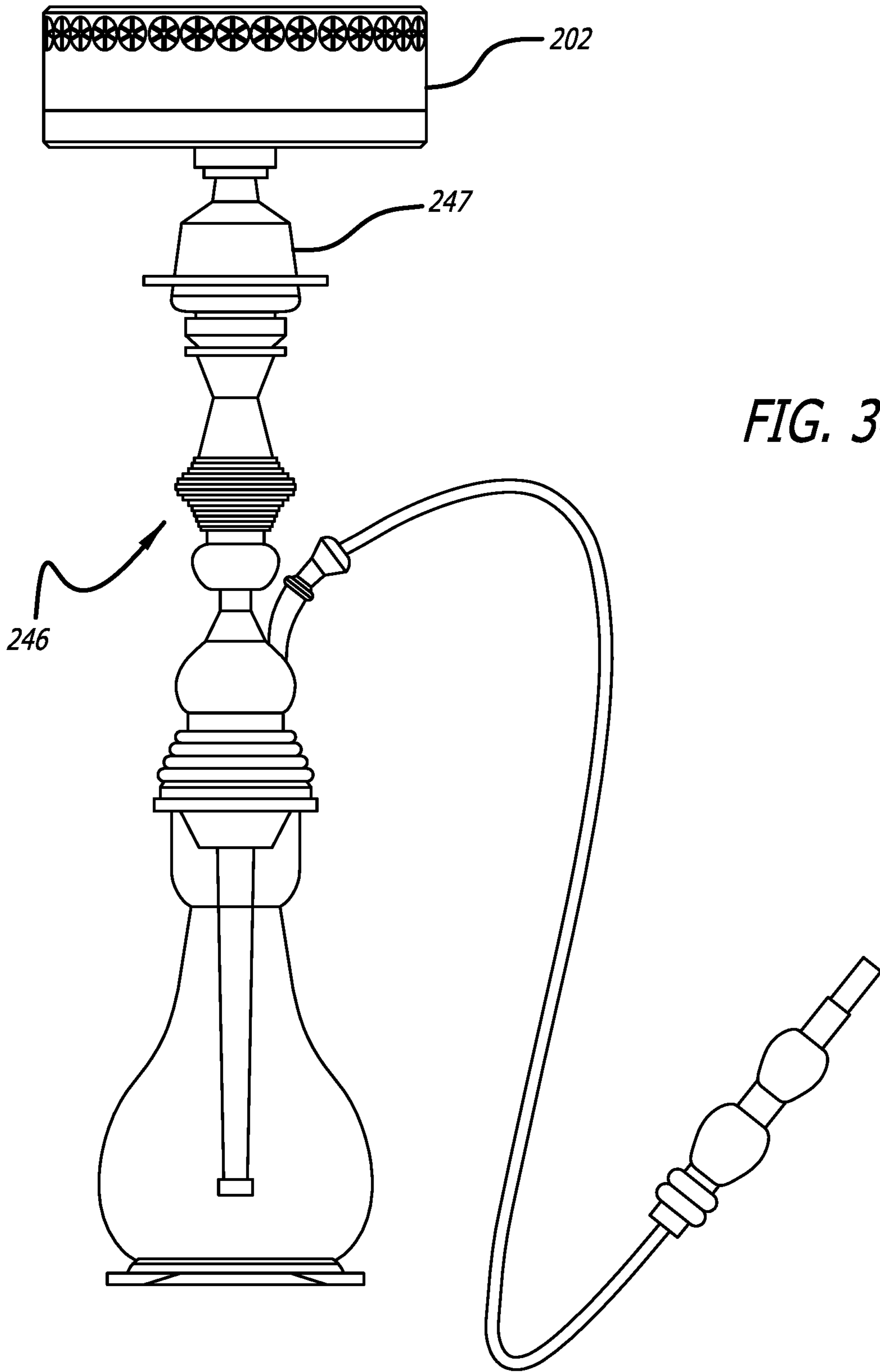


FIG. 33



*FIG. 34*

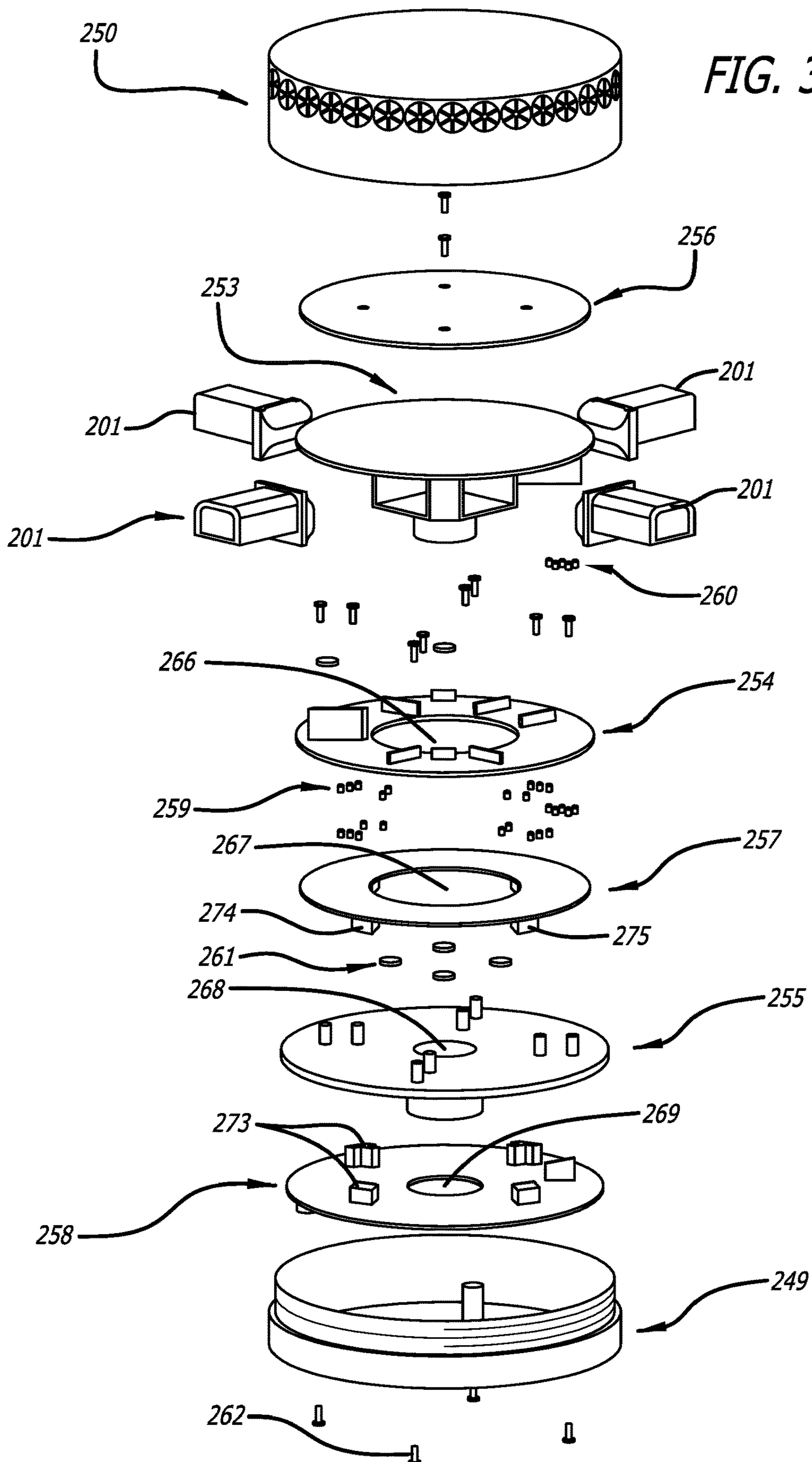


FIG. 35

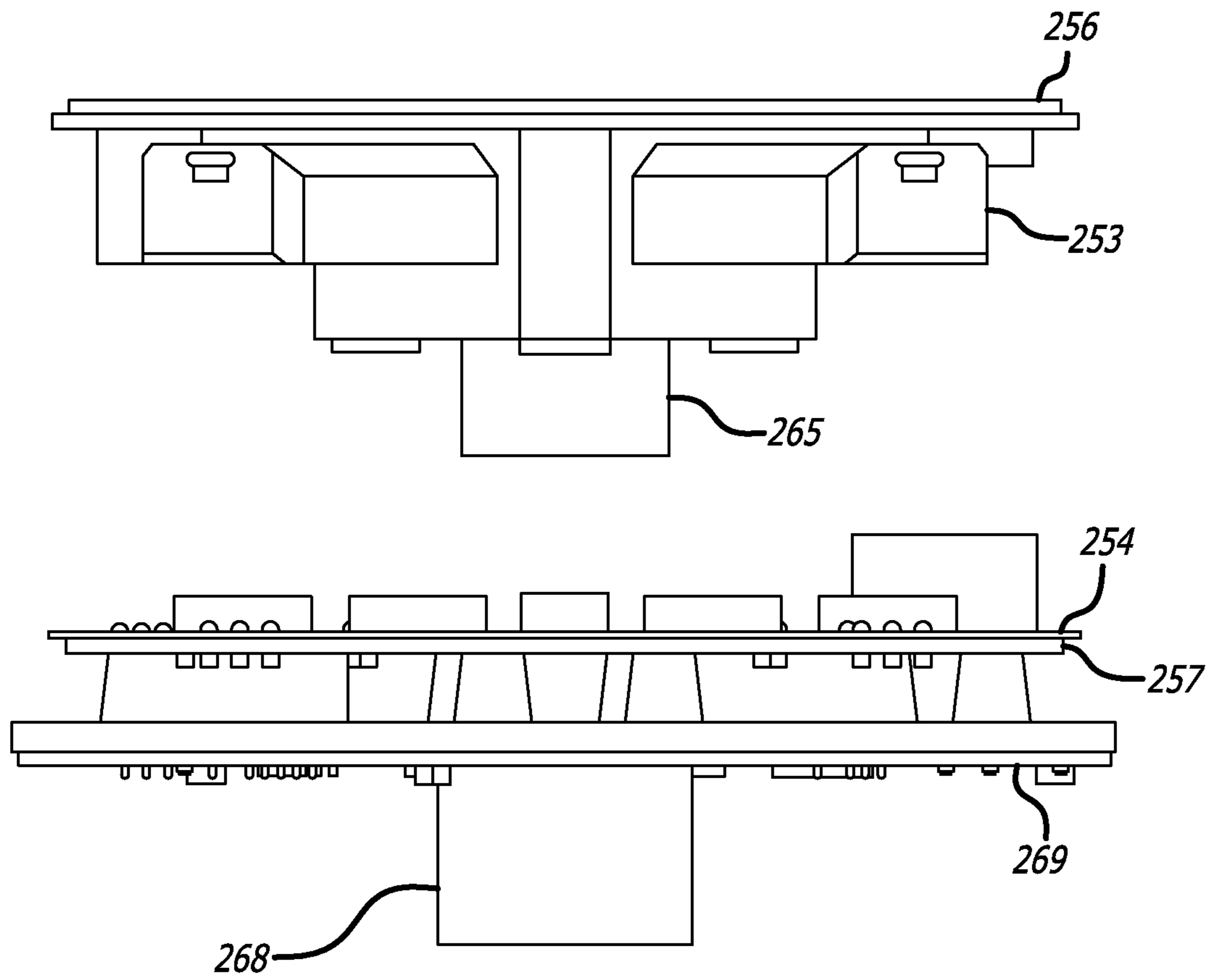


FIG. 36



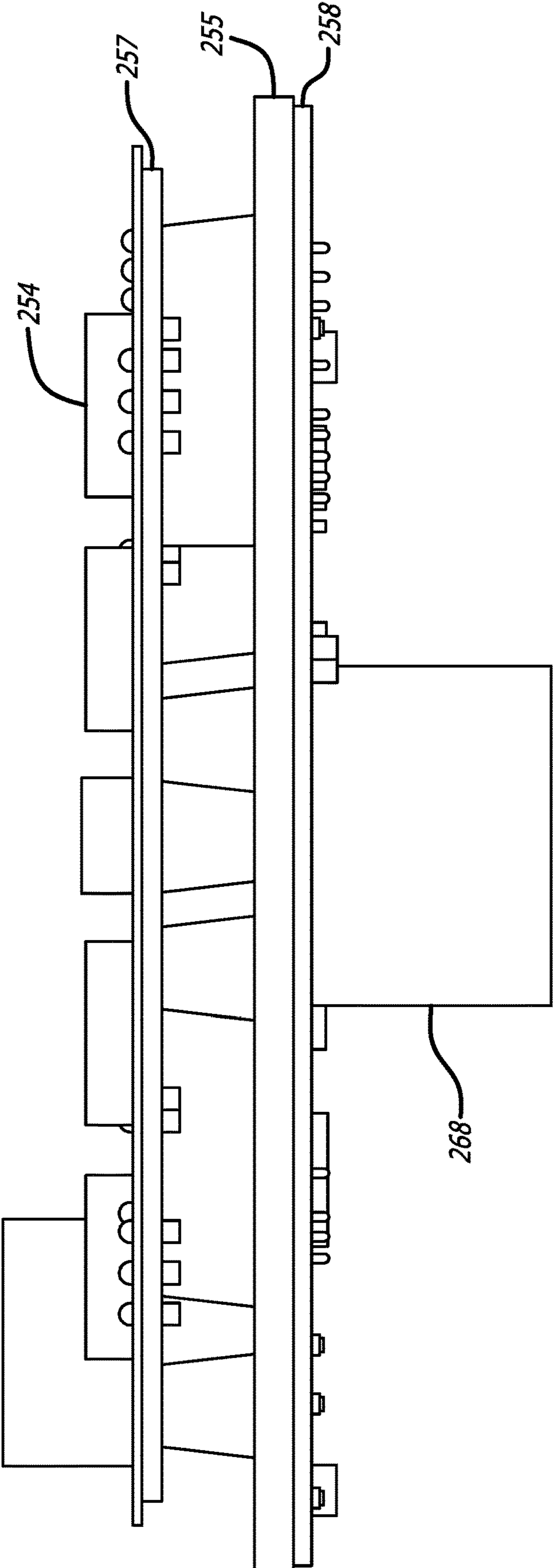


FIG. 37

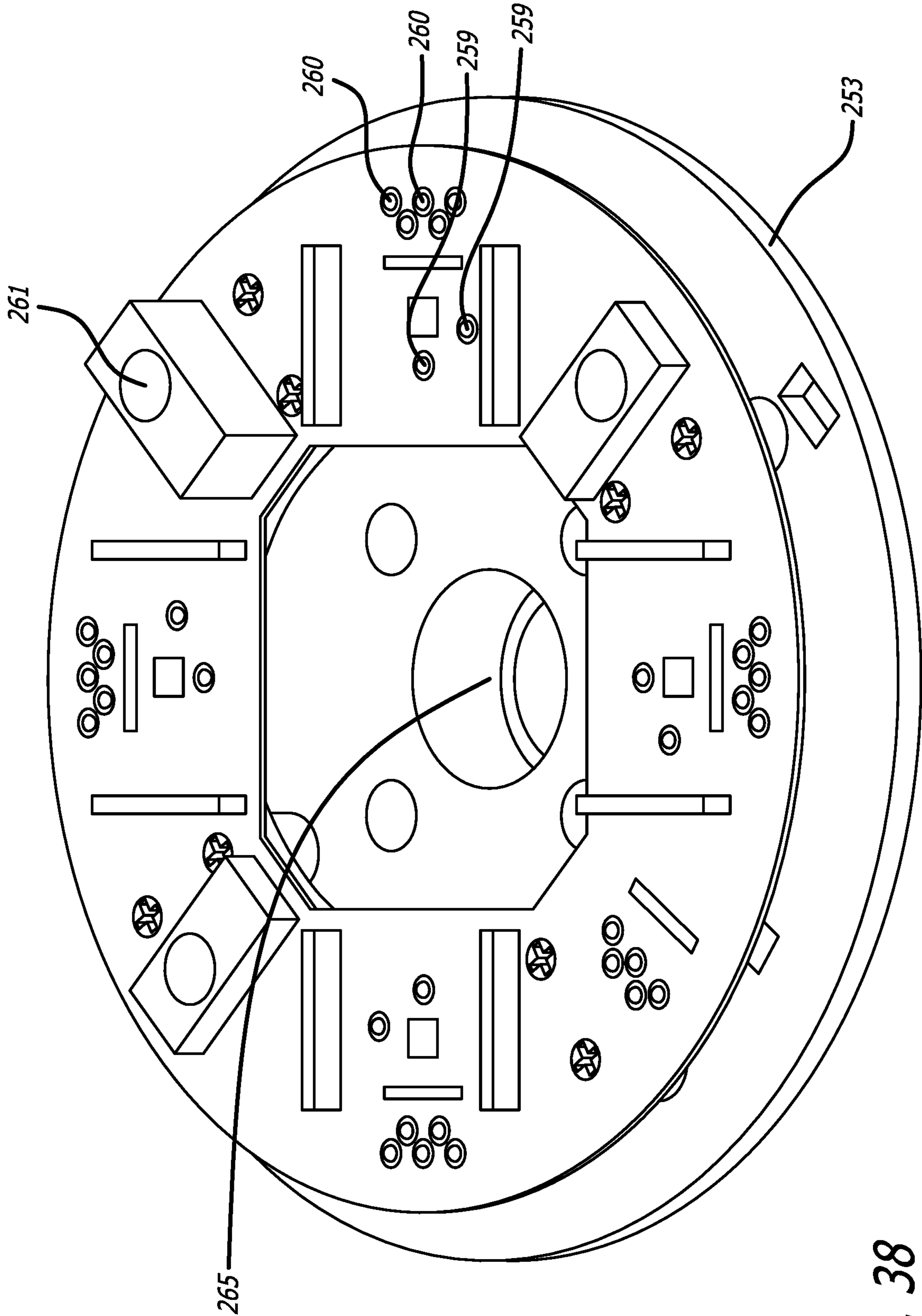


FIG. 38

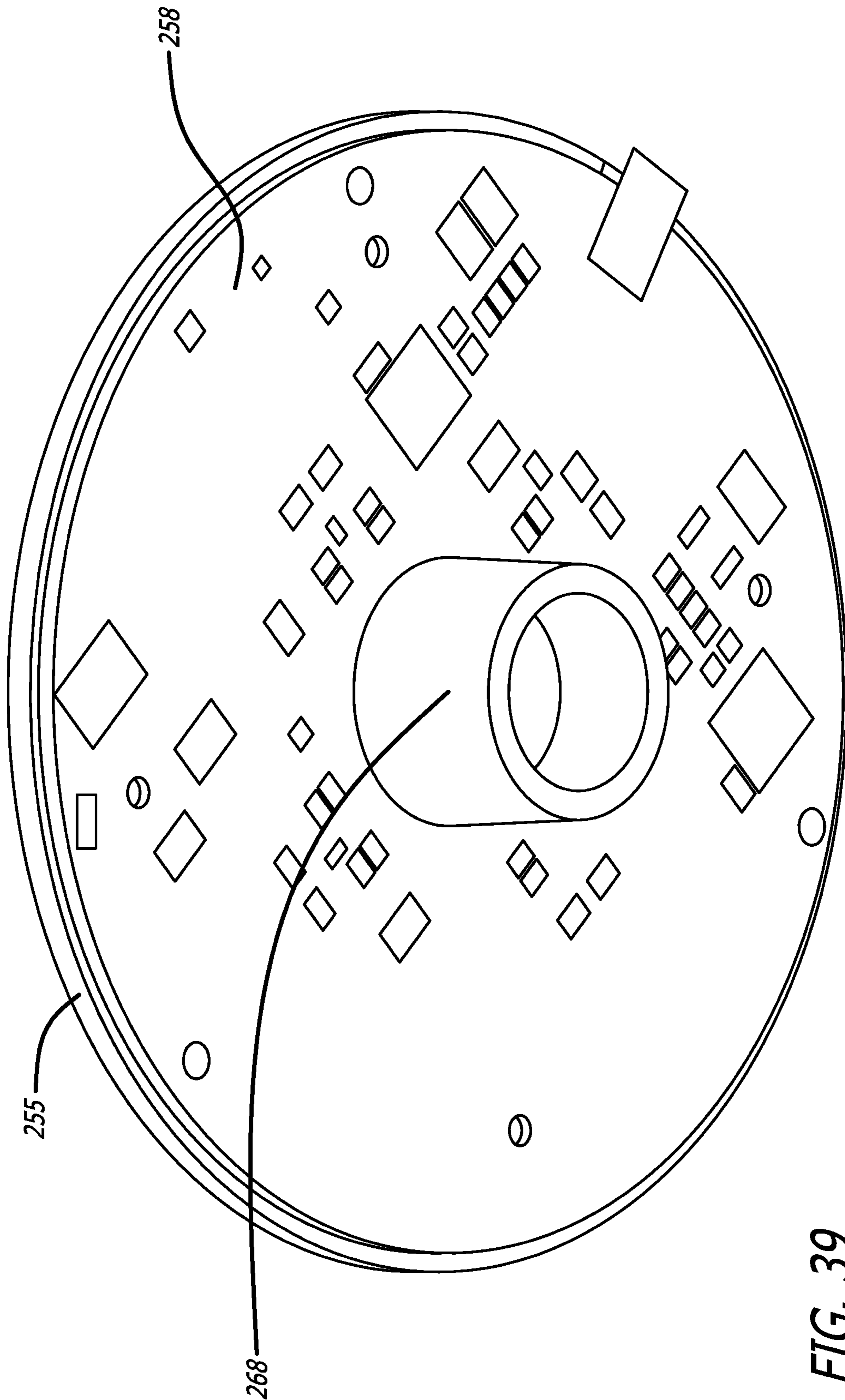


FIG. 39

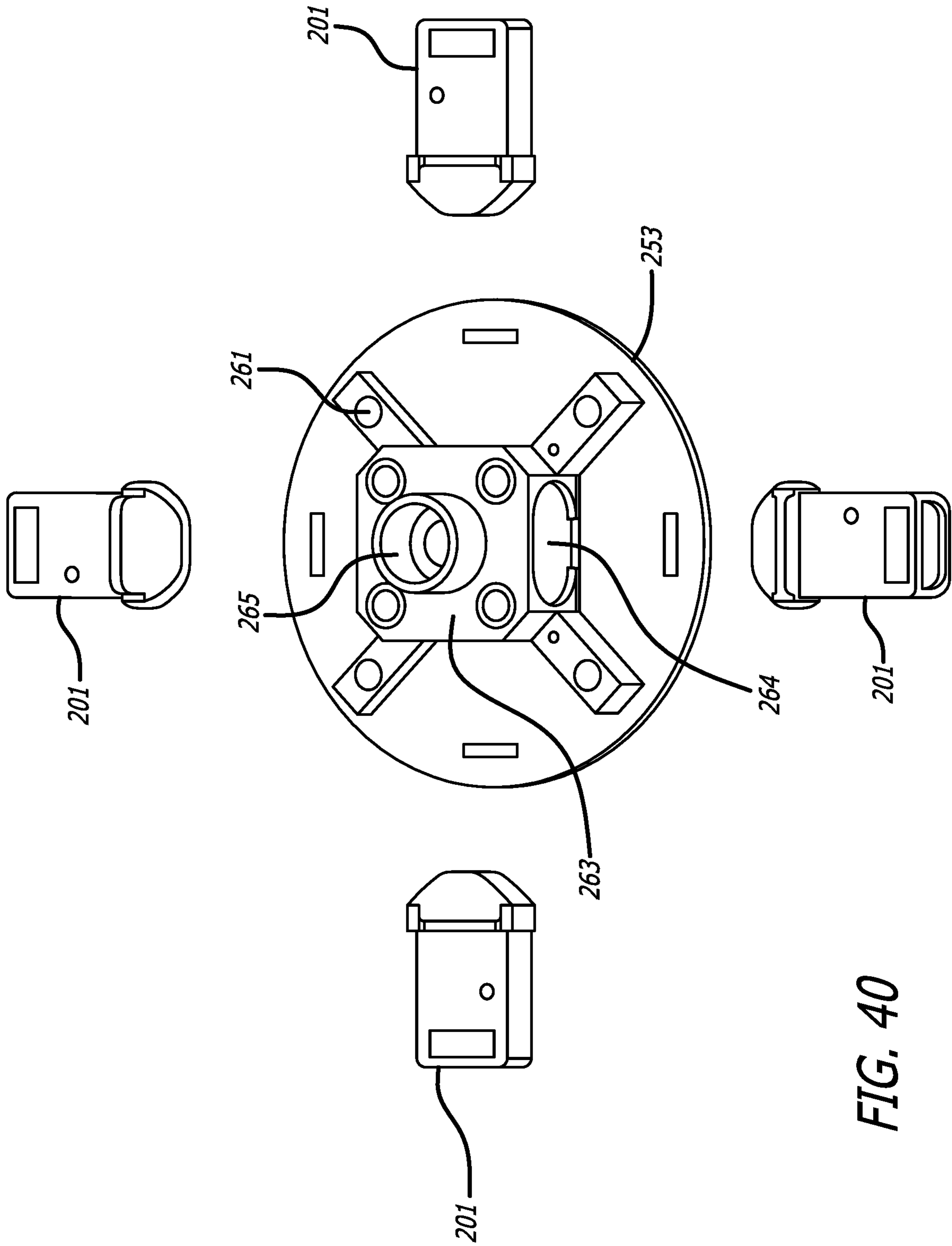


FIG. 40

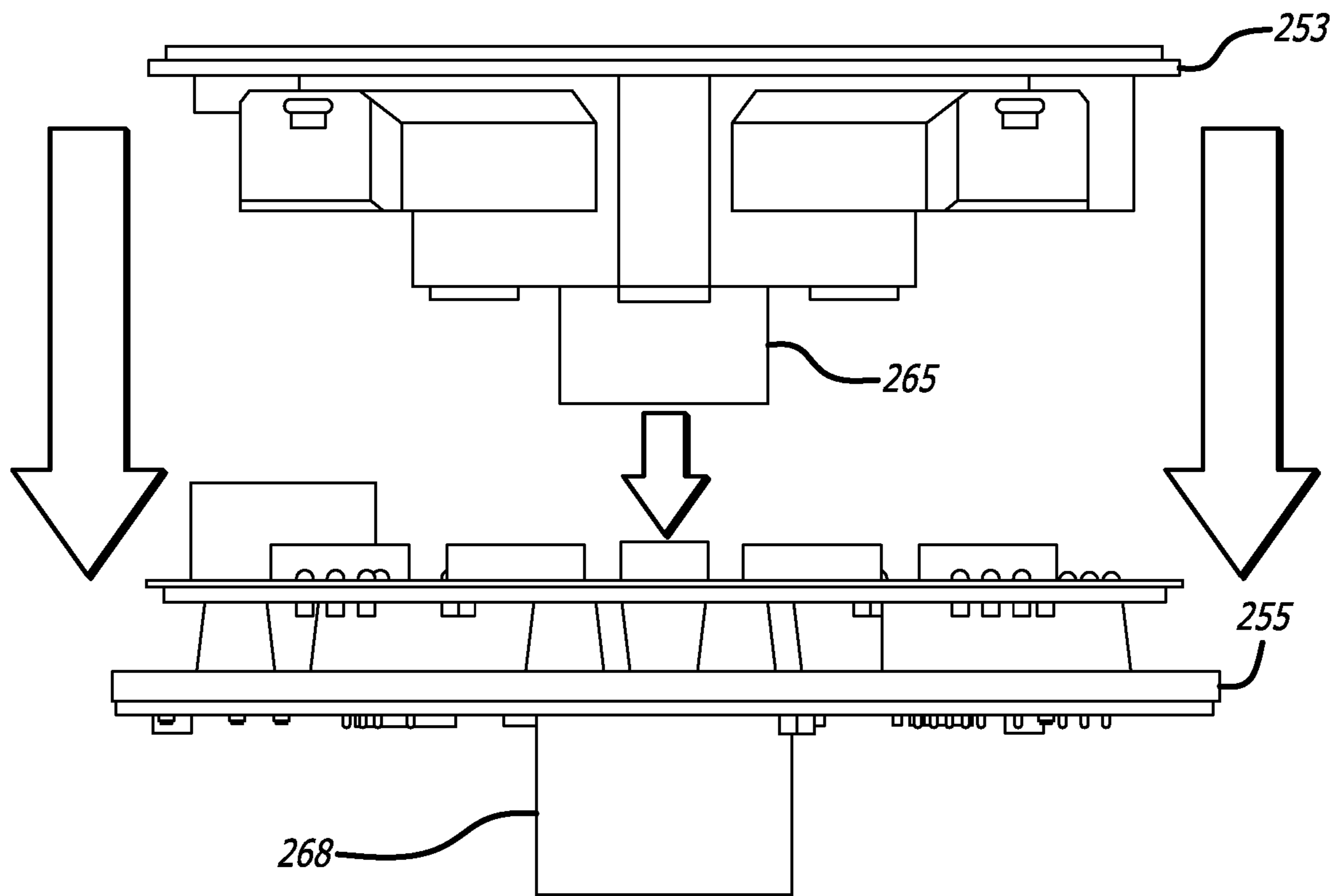


FIG. 41

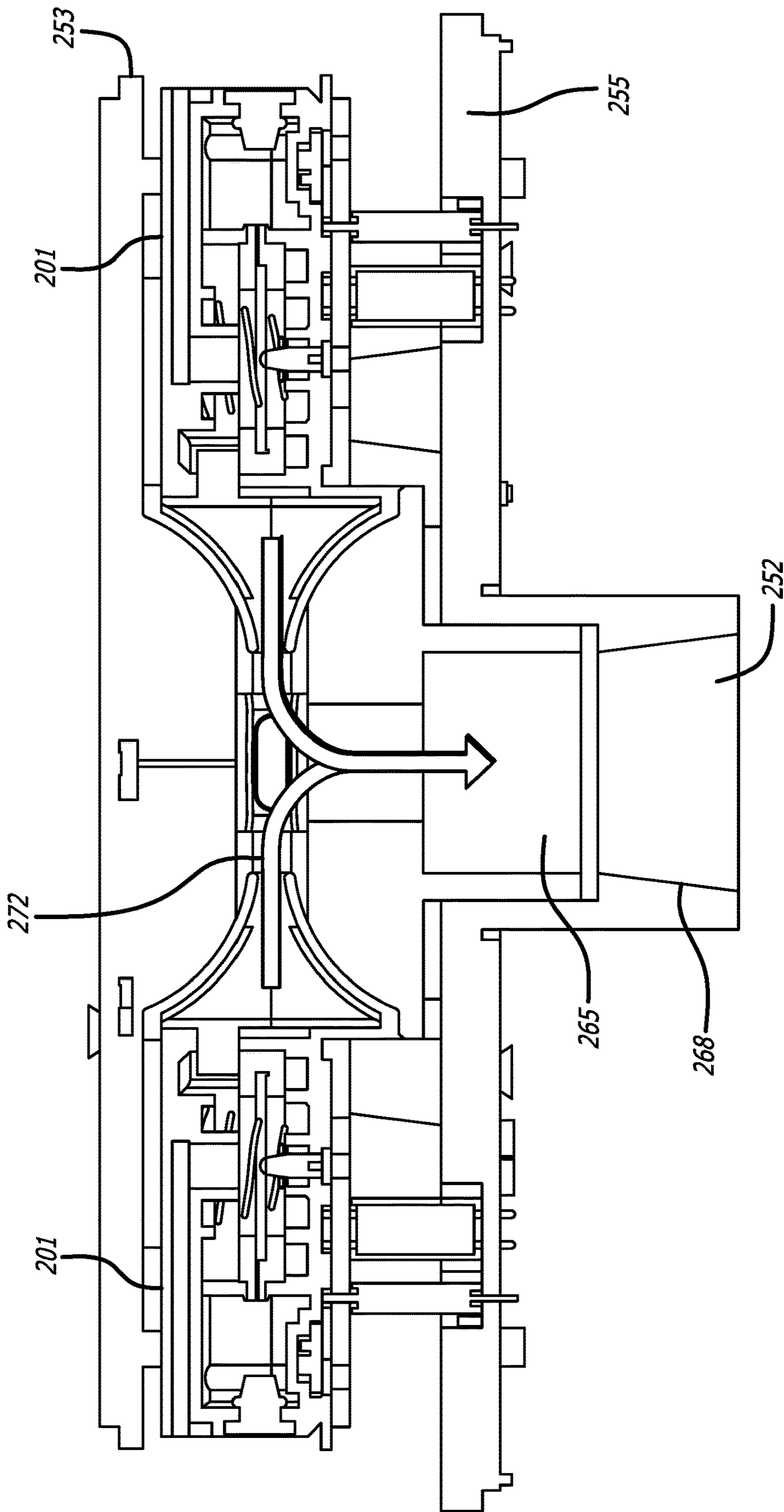
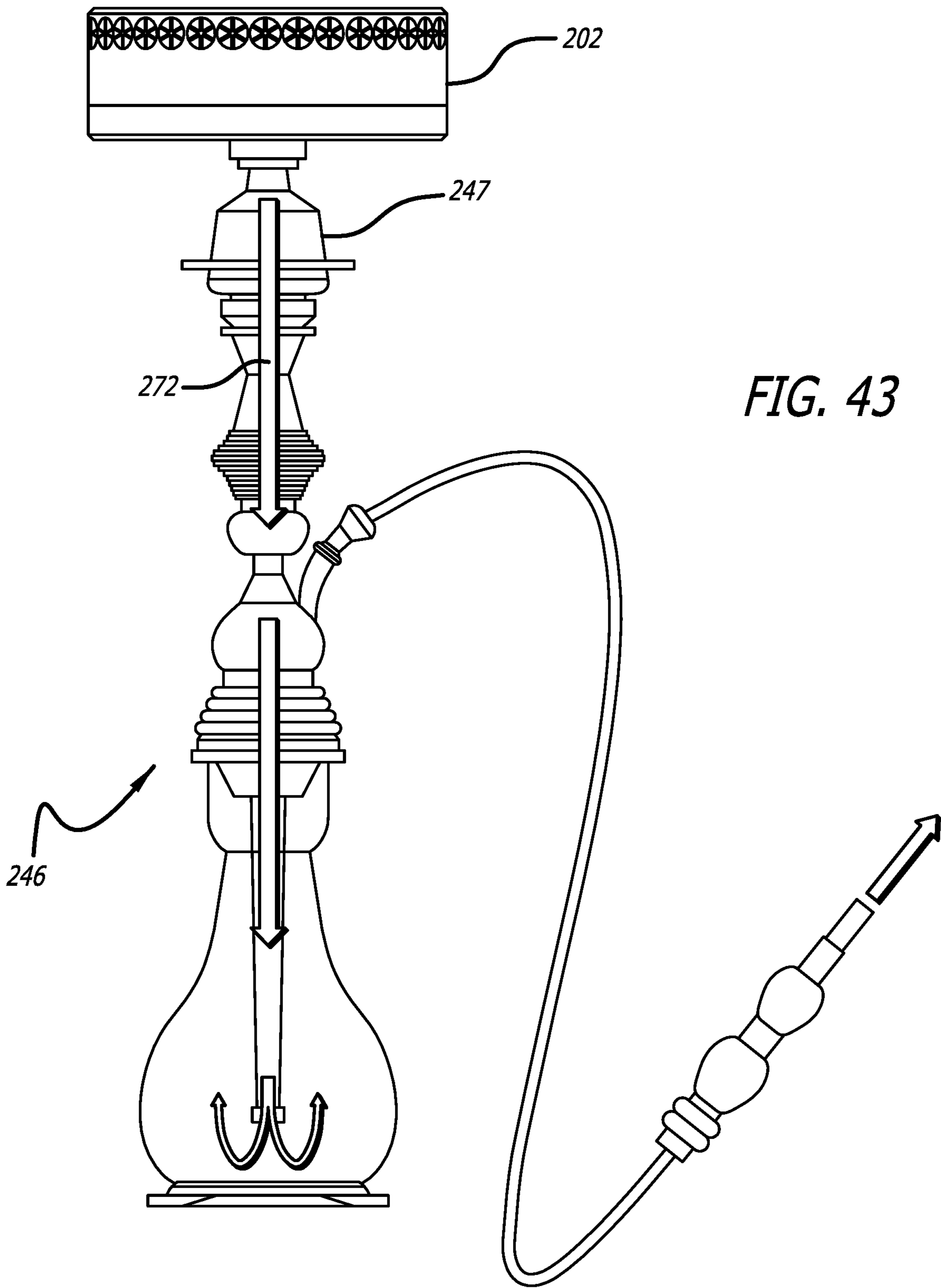


FIG. 42



**HOOKAH DEVICE****CROSS REFERENCES TO RELATED APPLICATIONS**

The present application claims the benefit of priority to and incorporates by reference herein the entirety of each of: European patent application no. 20168245.7, filed on 6 Apr. 2020; European patent application no. 20168231.7, filed on 6 Apr. 2020; and European patent application no. 20168938.7, filed on 9 Apr. 2020;

The present application is a continuation in part of U.S. patent application Ser. No. 16/889,667, filed on 1 Jun. 2020;

The present application is also a continuation in part of U.S. patent application Ser. No. 17/065,992, filed on 8 Oct. 2020, which itself is a continuation in part of U.S. patent application Ser. No. 16/889,667, filed on 1 Jun. 2020 and claims the benefit of priority to U.S. provisional patent application No. 63/064,386, filed on 11 Aug. 2020;

The present application is also a continuation in part of U.S. patent application Ser. No. 17/122,025, filed on 15 Dec. 2020 which itself claims the benefit of priority to International patent application nos. PCT/IB2019/060808, PCT/IB2019/060810, PCT/IB2019/060811, and PCT/IB2019/060812, all filed on 15 Dec. 2019; and

The present application is also a continuation in part of U.S. patent application Ser. No. 17/220,189, filed on 1 Apr. 2021, all of the foregoing applications are incorporated herein by reference in their entirety.

**FIELD**

The present invention relates to a hookah device. The present invention more particularly relates to a hookah device which generates a mist using ultrasonic vibrations.

**BACKGROUND**

The traditional hookah is a smoking device which burns tobacco leaves that have been crushed and prepared specifically to be heated using charcoal. The heat from the charcoal causes the crushed tobacco leaves to burn, producing smoke that is pulled through water in a glass chamber and to the user by inhalation. The water is used to cool the hot smoke for ease of inhalation.

Hookah use began centuries ago in ancient Persia and India. Today, hookah cafés are gaining popularity around the world, including the United Kingdom, France, Russia, the Middle East and the United States.

A typical modern hookah has a head (with holes in the bottom), a metal body, a water bowl and a flexible hose with a mouthpiece. New forms of electronic hookah products, including steam stones and hookah pens, have been introduced. These products are battery or mains powered and heat liquid containing nicotine, flavorings and other chemicals to produce smoke which is inhaled.

Although many users consider it less harmful than smoking cigarettes, hookah smoking has many of the same health risks as cigarette smoking.

Thus, a need exists in the art for an improved hookah device which seeks to address at least some of the problems described herein.

The present invention seeks to provide an improved hookah device.

**SUMMARY**

According to some arrangements, there is provided a hookah device comprising: a plurality of ultrasonic mist

generator devices which are each provided with a respective mist outlet port; a driver device which is connected electrically to each of the mist generator devices to activate the mist generator devices; and a hookah attachment arrangement which attaches the hookah device to a hookah, the hookah attachment arrangement having a hookah outlet port which provides a fluid flow path from the mist outlet ports of the mist generator devices and out of the hookah device such that, when at least one of the mist generator devices is activated by the driver device, mist generated by each activated mist generator device flows along the fluid flow path and out of the hookah device to the hookah.

In some arrangements, the driver device is connected electrically to each of the mist generator devices by a data bus and the driver device identifies and controls each mist generator device using a respective unique identifier for the mist generator device.

In some arrangements, each mist generator device comprises: an identification arrangement comprising: an integrated circuit having a memory which stores a unique identifier for the mist generator device; and an electrical connection which provides an electronic interface for communication with the integrated circuit.

In some arrangements, the driver device controls each respective mist generator device to activate independently of the other mist generator devices.

In some arrangements, the driver device controls the mist generator devices to activate in a predetermined sequence.

In some arrangements, each mist generator device comprises: a manifold having a manifold pipe which is in fluid communication with the mist outlet ports of the mist generator devices, wherein mist output from the mist outlet ports combines in the manifold pipe and flows through the manifold pipe and out from the hookah device.

In some arrangements, the hookah device comprises four mist generator devices which are releasably coupled to the manifold at 90° relative to one another.

In some arrangements, each mist generator device is releasably attached to the driver device so that each mist generator device is separable from the driver device.

In some arrangements, each mist generator device comprises: a mist generator housing which is elongate and comprises an air inlet port and the said mist outlet port; a liquid chamber provided within the mist generator housing, the liquid chamber containing a liquid to be atomized; a sonication chamber provided within the mist generator housing; a capillary element extending between the liquid chamber and the sonication chamber such that a first portion of the capillary element is within the liquid chamber and a second portion of the capillary element is within the sonication chamber; an ultrasonic transducer having a generally planar atomization surface which is provided within the sonication chamber, the ultrasonic transducer being mounted within the mist generator housing such that the plane of the atomization surface is substantially parallel with a longitudinal length of the mist generator housing, wherein part of the second portion of the capillary element is superimposed on part of the atomization surface, and wherein the ultrasonic transducer vibrates the atomization surface to atomize a liquid carried by the second portion of the capillary element to generate a mist comprising the atomized liquid and air within the sonication chamber; and an airflow arrangement which provides an air flow path between the air inlet port, the sonication chamber and the air outlet port.

In some arrangements, each mist generator device further comprises: a transducer holder which is held within the mist generator housing, wherein the transducer element holds the



ultrasonic transducer and retains the second portion of the capillary element superimposed on part of the atomization surface; and a divider portion which provides a barrier between the liquid chamber and the sonication chamber, wherein the divider portion comprises a capillary aperture through which part of the first portion of the capillary element extends.

In some arrangements, the capillary element is 100% bamboo fiber.

In some arrangements, the airflow arrangement changes the direction of a flow of air along the air flow path such that the flow of air is substantially perpendicular to the atomization surface of the ultrasonic transducer as the flow of air passes into the sonication chamber.

In some arrangements, the liquid chamber contains a liquid having a kinematic viscosity between 1.05 Pa·s and 1.412 Pa·s and a liquid density between 1.1 g/ml and 1.3 g/ml.

In some arrangements, the liquid chamber contains a liquid comprising approximately a 2:1 molar ratio of levulinic acid to nicotine.

In some arrangements, the driver device comprises: an AC driver which generates an AC drive signal at a predetermined frequency to drive a respective ultrasonic transducer in each mist generator device; an active power monitoring arrangement which monitors the active power used by the ultrasonic transducer when the ultrasonic transducer is driven by the AC drive signal, wherein the active power monitoring arrangement provides a monitoring signal which is indicative of an active power used by the ultrasonic transducer; a processor controlling the AC driver and receiving the monitoring signal drive from the active power monitoring arrangement; and a memory storing instructions which, when executed by the processor, cause the processor to:

- A. control the AC driver to output an AC drive signal to the ultrasonic transducer at a predetermined sweep frequency;
- B. calculate the active power being used by the ultrasonic transducer based on the monitoring signal;
- C. control the AC driver to modulate the AC drive signal to maximize the active power being used by the ultrasonic transducer;
- D. store a record in the memory of the maximum active power used by the ultrasonic transducer and the sweep frequency of the AC drive signal;
- E. repeat steps A-D for a predetermined number of iterations with the sweep frequency incrementing with each iteration such that, after the predetermined number of iterations has occurred, the sweep frequency has been incremented from a start sweep frequency to an end sweep frequency;
- F. identify from the records stored in the memory the optimum frequency for the AC drive signal which is the sweep frequency of the AC drive signal at which a maximum active power is used by the ultrasonic transducer; and
- G. control the AC driver to output an AC drive signal to the ultrasonic transducer at the optimum frequency to drive the ultrasonic transducer to atomize a liquid.

In some arrangements, the active power monitoring arrangement comprises: a current sensing arrangement which senses a drive current of the AC drive signal driving the ultrasonic transducer, wherein the active power monitoring arrangement provides a monitoring signal which is indicative of the sensed drive current.

In some arrangements, the memory stores instructions which, when executed by the processor, cause the processor to: repeat steps A-D with the sweep frequency being incremented from a start sweep frequency of 2900 kHz to an end sweep frequency of 2960 kHz.

In some arrangements, the memory stores instructions which, when executed by the processor, cause the processor to: repeat steps A-D with the sweep frequency being incremented from a start sweep frequency of 2900 kHz to an end sweep frequency of 3100 kHz.

In some arrangements, the AC driver modulates the AC drive signal by pulse width modulation to maximize the active power being used by the ultrasonic transducer.

According to some arrangements, there is provided a hookah comprising: a water chamber; an elongate stem having a first end which is attached to the water chamber, the stem comprising a mist flow path which extends from a second end of the stem, through the stem, to the first end; and a hookah device comprising: a plurality of ultrasonic mist generator devices which are each provided with a respective mist outlet port; a driver device which is connected electrically to each of the mist generator devices to activate the mist generator devices; and a hookah attachment arrangement which is attached to the stem at the second end of the stem, the hookah attachment arrangement having a hookah outlet port which provides a fluid flow path from the mist outlet ports of the mist generator devices and out of the hookah device such that, when at least one of the mist generator devices is activated by the driver device, mist generated by each activated mist generator device flows along the fluid flow path, out of the hookah device, through the mist flow path in the stem and into the water chamber.

#### BRIEF DESCRIPTION OF THE DRAWINGS

So that the present invention may be more readily understood, embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is an exploded view of components of an ultrasonic mist inhaler.

FIG. 2 is an exploded view of components of an inhaler liquid reservoir structure.

FIG. 3 is a cross section view of components of an inhaler liquid reservoir structure.

FIG. 4A is an isometric view of an airflow member of the inhaler liquid reservoir structure according to FIGS. 2 and 3.

FIG. 4B is a cross section view of the airflow member shown in FIG. 4A.

FIG. 5 is schematic diagram showing a piezoelectric transducer modelled as an RLC circuit.

FIG. 6 is graph of frequency versus log impedance of an RLC circuit.

FIG. 7 is graph of frequency versus log impedance showing inductive and capacitive regions of operation of a piezoelectric transducer.

FIG. 8 is flow diagram showing the operation of a frequency controller.

FIG. 9 is a diagrammatic perspective view of a mist generator device of this disclosure.

FIG. 10 is a diagrammatic perspective view of a mist generator device of this disclosure.

FIG. 11 is a diagrammatic exploded perspective view of a mist generator device of this disclosure.

FIG. 12 is a diagrammatic perspective view of a transducer holder of this disclosure.

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FIG. 13 is a diagrammatic perspective view of a transducer holder of this disclosure.

FIG. 14 is a diagrammatic perspective view of a capillary element of this disclosure.

FIG. 15 is a diagrammatic perspective view of a capillary element of this disclosure.

FIG. 16 is a diagrammatic perspective view of a transducer holder of this disclosure.

FIG. 17 is a diagrammatic perspective view of a transducer holder of this disclosure.

FIG. 18 is a diagrammatic perspective view of a part of a housing of this disclosure.

FIG. 19 is a diagrammatic perspective view of an absorbent element of this disclosure.

FIG. 20 is a diagrammatic perspective view of a part of a housing of this disclosure.

FIG. 21 is a diagrammatic perspective view of a part of a housing of this disclosure.

FIG. 22 is a diagrammatic perspective view of an absorbent element of this disclosure.

FIG. 23 is a diagrammatic perspective view of a part of a housing of this disclosure.

FIG. 24 is a diagrammatic perspective view of a part of a housing of this disclosure.

FIG. 25 is a diagrammatic perspective view of a part of a housing of this disclosure.

FIG. 26 is a diagrammatic perspective view of a circuit board of this disclosure.

FIG. 27 is a diagrammatic perspective view of a circuit board of this disclosure.

FIG. 28 is a diagrammatic exploded perspective view of a mist generator device of this disclosure.

FIG. 29 is a diagrammatic exploded perspective view of a mist generator device of this disclosure.

FIG. 30 is a cross sectional view of a mist generator device of this disclosure.

FIG. 31 is a cross sectional view of a mist generator device of this disclosure.

FIG. 32 is a cross sectional view of a mist generator device of this disclosure.

FIG. 33 is a diagrammatic perspective view of a hookah device of this disclosure.

FIG. 34 is a diagrammatic perspective view of a hookah device of this disclosure attached to a hookah body and water bowl of a hookah apparatus.

FIG. 35 is a diagrammatic exploded perspective view of a hookah device of this disclosure.

FIG. 36 is a diagrammatic perspective view of components of a hookah device of this disclosure.

FIG. 37 is a diagrammatic perspective view of components of a hookah device of this disclosure.

FIG. 38 is a diagrammatic perspective view of a component of a hookah device of this disclosure.

FIG. 39 is a diagrammatic perspective view of a component of a hookah device of this disclosure.

FIG. 40 is a diagrammatic perspective view of a component of a hookah device and four mist generator devices of this disclosure.

FIG. 41 is a diagrammatic perspective view of components of a hookah device of this disclosure.

FIG. 42 is a diagrammatic cross-sectional view of components of a hookah device of this disclosure.

FIG. 43 is a diagrammatic perspective view of a hookah device of this disclosure attached to a hookah body and water bowl of a hookah apparatus.

## DETAILED DESCRIPTION

Aspects of the present disclosure are best understood from the following detailed description when read with the

## 6

accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. Specific examples of components, concentrations, applications and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the attachment of a first feature and a second feature in the description that follows may include embodiments in which the first feature and the second feature are attached in direct contact, and may also include embodiments in which additional features may be positioned between the first feature and the second feature, such that the first feature and the second feature may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

The following disclosure describes representative arrangements or examples. Each arrangement or example may be considered to be an embodiment and any reference to an “arrangement” or an “example” may be changed to “embodiment” in the present disclosure.

A hookah device of some arrangements incorporates ultrasonic aerosolization technology. The hookah device of some arrangements is configured to replace a conventional hookah head (coal-heated or electronically heated). The hookah device of some arrangements releasably attaches to an existing stem or metal body and water chamber/bowl in place of the conventional hookah head which houses the tobacco and the charcoal (or electronic heating element).

In other arrangements, the hookah device is provided with a stem/body and a water chamber/bowl as a complete hookah apparatus.

Hookah water bowls come in various shapes and sizes, ornamented with traditional or futuristic decorations as per individual preferences. The design and development of the ultrasonic aerosolizing hookah device of some arrangements was executed, keeping the tradition in mind, to create a replaceable head that fits onto any existing hookah.

The following disclosure describes the components and functionality of an ultrasonic mist generator device. The disclosure then describes the hookah device of some arrangements which incorporates a plurality of ultrasonic mist generator devices.

Conventional electronic vaporizing inhalers tend to rely on inducing high temperatures of a metal component configured to heat a liquid in the inhaler, thus vaporizing the liquid that can be breathed in. The liquid typically contains nicotine and flavorings blended into a solution of propylene glycol (PG) and vegetable glycerin (VG), which is vaporized via a heating component at high temperatures. Problems with conventional inhalers may include the possibility of burning metal and subsequent breathing in of the metal along with the burnt liquid. In addition, some may not prefer the burnt smell or taste caused by the heated liquid.

FIGS. 1 to 4 illustrate an ultrasonic mist inhaler comprising a sonication chamber. It is noted that the expression “mist” used in the following disclosure means the liquid is not heated as usually in traditional inhalers known from the prior art. In fact, traditional inhalers use heating elements to

heat the liquid above its boiling temperature to produce a vapor, which is different from a mist.

When sonicating liquids at high intensities, the sound waves that propagate into the liquid media result in alternating high-pressure (compression) and low-pressure (rarefaction) cycles, at different rates depending on the frequency. During the low-pressure cycle, high-intensity ultrasonic waves create small vacuum bubbles or voids in the liquid. This phenomenon is termed cavitation. When the bubbles attain a volume at which they can no longer absorb energy, they collapse violently during a high-pressure cycle. During the implosion, very high pressures are reached locally. At cavitation, broken capillary waves are generated, and tiny droplets break the surface tension of the liquid and are quickly released into the air, taking mist form.

The following will explain more precisely the cavitation phenomenon.

When the liquid is atomized by ultrasonic vibrations, micro water bubbles are produced in the liquid.

The bubble production is a process of formation of cavities created by the negative pressure generated by intense ultrasonic waves generated by the means of ultrasonic vibrations.

High intensity ultrasonic sound waves leading to rapid growth of cavities with relatively low and negligible reduction in cavity size during the positive pressure cycle.

Ultrasound waves, like all sound waves, consist of cycles of compression and expansion. When in contact with a liquid, Compression cycles exert a positive pressure on the liquid, pushing the molecules together. Expansion cycles exert a negative pressure, pulling the molecules away from another.

Intense ultrasound waves create regions of positive pressure and negative pressure. A cavity can form and grow during the episodes of negative pressure. When the cavity attains a critical size, the cavity implodes.

The amount of negative pressure needed depends on the type and purity of the liquid. For truly pure liquids, tensile strengths are so great that available ultrasound generators cannot produce enough negative pressure to make cavities. In pure water, for instance, more than 1,000 atmospheres of negative pressure would be required, yet the most powerful ultrasound generators produce only about 50 atmospheres of negative pressure. The tensile strength of liquids is reduced by the gas trapped within the crevices of the liquid particles. The effect is analogous to the reduction in strength that occurs from cracks in solid materials. When a crevice filled with gas is exposed to a negative-pressure cycle from a sound wave, the reduced pressure makes the gas in the crevice expand until a small bubble is released into solution.

However, a bubble irradiated with ultrasound continually absorbs energy from alternating compression and expansion cycles of the sound wave. These cause the bubbles to grow and contract, striking a dynamic balance between the void inside the bubble and the liquid outside. In some cases, ultrasonic waves will sustain a bubble that simply oscillates in size. In other cases, the average size of the bubble will increase.

Cavity growth depends on the intensity of sound. High-intensity ultrasound can expand the cavity so rapidly during the negative-pressure cycle that the cavity never has a chance to shrink during the positive-pressure cycle. In this process, cavities can grow rapidly in the course of a single cycle of sound.

For low-intensity ultrasound the size of the cavity oscillates in phase with the expansion and compression cycles. The surface of a cavity produced by low-intensity ultrasound

is slightly greater during expansion cycles than during compression cycles. Since the amount of gas that diffuses in or out of the cavity depends on the surface area, diffusion into the cavity during expansion cycles will be slightly greater than diffusion out during compression cycles. For each cycle of sound, then, the cavity expands a little more than it shrinks. Over many cycles the cavities will grow slowly.

It has been noticed that the growing cavity can eventually reach a critical size where it will most efficiently absorb energy from the ultrasound. The critical size depends on the frequency of the ultrasound wave. Once a cavity has experienced a very rapid growth caused by high intensity ultrasound, it can no longer absorb energy as efficiently from the sound waves. Without this energy input the cavity can no longer sustain itself. The liquid rushes in and the cavity implodes due to a non-linear response.

The energy released from the implosion causes the liquid to be fragmented into microscopic particles which are dispersed into the air as mist.

The equation for description of the above non-linear response phenomenon may be described by the "Rayleigh-Plesset" equation. This equation can be derived from the "Navier-Stokes" equation used in fluid dynamics.

The inventors approach was to rewrite the "Rayleigh-Plesset" equation in which the bubble volume, V, is used as the dynamic parameter and where the physics describing the dissipation is identical to that used in the more classical form where the radius is the dynamic parameter.

The equation used derived as follows:

$$\left| \frac{1}{c^2} \frac{\delta^2 \phi}{\delta t^2} \right| \sim \left( \frac{R}{\lambda} \right)^2 \ll 1$$

$$\frac{1}{4\pi} \left( \frac{4\pi}{3V} \right)^{\frac{1}{3}} \left( \dot{V} - \frac{\dot{V}^2(t)}{6V} \right) =$$

$$\frac{1}{\rho_0} \left( \left( p_0 + 2\sigma \left( \frac{4\pi}{3V_0} \right)^{\frac{1}{3}} - p_V \right) \left( \frac{V_0}{V} \right)^\kappa + p_V - 2\sigma \left( \frac{4\pi}{3V} \right)^{\frac{1}{3}} - p_0 - P(t) \right)$$

wherein:

V is the bubble volume

V<sub>0</sub> is the equilibrium bubble volume

ρ<sub>0</sub> is the liquid density (assumed to be constant)

σ is the surface tension

p<sub>V</sub> is the vapor pressure

p<sub>0</sub> is the static pressure in the liquid just outside the bubble wall

κ is the polytropic index of the gas

t is the time

R(t) is the bubble radius

P(t) is the applied pressure

c is the speed sound of the liquid

φ is the velocity potential

λ is the wavelength of the insonifying field

In the ultrasonic mist inhaler, the liquid has a kinematic viscosity between 1.05 Pa·sec and 1.412 Pa·sec.

By solving the above equation with the right parameters of viscosity, density and having a desired target bubble volume of liquid spray into the air, it has been found that the frequency range of 2.8 MHz to 3.2 MHz for liquid viscosity range of 1.05 Pa·s and 1.412 Pa·s produce a bubble volume of about 0.25 to 0.5 microns.

The process of ultrasonic cavitation has a significant impact on the nicotine concentration in the produced mist.

No heating elements are involved, thereby leading to no burnt elements and reducing second-hand smoke effects.

In some arrangements, said liquid comprises 57-70% (w/w) vegetable glycerin and 30-43% (w/w) propylene glycol, said propylene glycol including nicotine and optionally flavorings.

In the ultrasonic mist inhaler, a capillary element may extend between the sonication chamber and the liquid chamber.

In the ultrasonic mist inhaler, the capillary element is a material at least partly in bamboo fibers.

The capillary element allows a high absorption capacity, a high rate of absorption as well as a high fluid-retention ratio.

It was found that the inherent properties of the proposed material used for the capillarity have a significant impact on the efficient functioning of the ultrasonic mist inhaler.

Further, inherent properties of the proposed material include a good hygroscopicity while maintaining a good permeability. This allows the drawn liquid to efficiently permeate the capillary while the observed high absorption capacity allows the retention of a considerable amount of liquid thus allowing the ultrasonic mist inhaler to last for a longer time when compared with the other products available in the market.

Another significant advantage of using the bamboo fibers is the naturally occurring antimicrobial bio-agent namely "Kun" inherently present within the bamboo fiber making it antibacterial, anti-fungal and odor resistant, making it suitable for medical applications.

The inherent properties have been verified using numerical analysis regarding the benefits of the bamboo fiber for sonication.

The following formulae have been tested with bamboo fibers material and others material such cotton, paper, or other fiber strands for the use as capillary element and demonstrates that bamboo fibers have much better properties for the use in sonication:

$$C = A + \frac{T}{W_f} - \frac{1}{P_f} + (1 - \alpha) \frac{V_d}{W_f}$$

wherein:

C (cc/gm of fluid/gm) is the volume per mass of the liquid absorbed divided by the dry mass of the capillary element,

A (cm<sup>2</sup>) is the total surface area of the capillary element

T (cm) is the thickness of the capillary element,

W<sub>f</sub> (gm) is the mass of the dry capillary element,

P<sub>f</sub> (cc/g-sec) is the density of the dry capillary element,

α is the ratio of increase in volume of capillary element upon wetting to the volume of liquid diffused in the capillary element,

V<sub>d</sub> (cc) is the amount of liquid diffused in the capillary element,

$$\text{Absorbent Rate, } Q = \frac{\pi r \gamma \cos \theta}{2\eta} \cdot \left( \frac{T}{W_f} - \frac{1}{AP_f} \right)$$

Q (cc/sec) is the amount of liquid absorbed per unit time,

r (cm) is the radius of the pores within the capillary element,

γ (N/m) is the surface tension of the liquid,

θ (degrees) is the angle of contact of the fiber,

η (m<sup>2</sup>/sec) is the viscosity of the fluid.

FIG. 1 depicts a disposable ultrasonic mist inhaler 100. As can be seen in FIG. 1, the ultrasonic mist inhaler 100 has a cylindrical body with a relatively long length as compared to the diameter. In terms of shape and appearance, the ultrasonic mist inhaler 100 is designed to mimic the look of a typical cigarette. For instance, the inhaler can feature a first portion 101 that primarily simulates the tobacco rod portion of a cigarette and a second portion 102 that primarily simulates a filter. In the disposable arrangement, the first portion and second portion are regions of a single, but-separable device. The designation of a first portion 101 and a second portion 102 is used to conveniently differentiate the components that are primarily contained in each portion.

As can be seen in FIG. 1, the ultrasonic mist inhaler comprises a mouthpiece 1, a liquid reservoir structure 2 and a casing 3. The first portion 101 comprises the casing 3 and the second portion 102 comprises the mouthpiece 1 and the reservoir structure 2.

The first portion 101 contains the power supply energy.

An electrical storage device 30 powers the ultrasonic mist inhaler 100. The electrical storage device 30 can be a battery, including but not limited to a lithium-ion, alkaline, zinc-carbon, nickel-metal hydride, or nickel-cadmium battery; a super capacitor; or a combination thereof. In the disposable arrangement, the electrical storage device 30 is not rechargeable, but, in the reusable arrangement, the electrical storage device 30 would be selected for its ability to recharge. In the disposable arrangement, the electrical storage device 30 is primarily selected to deliver a constant voltage over the life of the inhaler 100. Otherwise, the performance of the inhaler would degrade over time. Preferred electrical storage devices that are able to provide a consistent voltage output over the life of the device include lithium-ion and lithium polymer batteries.

The electrical storage device 30 has a first end 30a that generally corresponds to a positive terminal and a second end 30b that generally corresponds to a negative terminal. The negative terminal is extending to the first end 30a.

Because the electrical storage device 30 is located in the first portion 101 and the liquid reservoir structure 2 is located in the second portion 102, the joint needs to provide electrical communication between those components. Electrical communication is established using at least an electrode or probe that is compressed together when the first portion 101 is tightened into the second portion 102.

In order for the device to be reusable, the electrical storage device 30 is rechargeable. The casing 3 contains a charging port 32.

The integrated circuit 4 has a proximal end 4a and a distal end 4b. The positive terminal at the first end 30a of the electrical storage device 30 is in electrical communication with a positive lead of the flexible integrated circuit 4. The negative terminal at the second end 30b of the electrical storage device 30 is in electrical communication with a negative lead of the integrated circuit 4. The distal end 4b of the integrated circuit 4 comprises a microprocessor. The microprocessor is configured to process data from a sensor, to control a light, to direct current flow to means of ultrasonic vibrations 5 in the second portion 102, and to terminate current flow after a pre-programmed amount of time.

The sensor detects when the ultrasonic mist inhaler 100 is in use (when the user draws on the inhaler) and activates the microprocessor. The sensor can be selected to detect changes in pressure, air flow, or vibration. In one arrangement, the sensor is a pressure sensor. In the digital device, the sensor takes continuous readings which in turn requires the digital

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sensor to continuously draw current, but the amount is small and overall battery life would be negligibly affected.

In some arrangements, the integrated circuit 4 comprises a H bridge, which may be formed by 4 MOSFETs to convert a direct current into an alternate current at high frequency.

Referring to FIG. 2 and FIG. 3, illustrations of a liquid reservoir structure 2 according to an arrangement are shown. The liquid reservoir structure 2 comprises a liquid chamber 21 adapted to receive liquid to be atomized and a sonication chamber 22 in fluid communication with the liquid chamber 21.

In the arrangement shown, the liquid reservoir structure 2 comprises an inhalation channel 20 providing an air passage from the sonication chamber 22 toward the surroundings.

As an arrangement of sensor position, the sensor may be located in the sonication chamber 22.

The inhalation channel 20 has a frustoconical element 20a and an inner container 20b.

As depicted in FIGS. 4A and 4B, further the inhalation channel 20 has an airflow member 27 for providing air flow from the surroundings to the sonication chamber 22.

The airflow member 27 has an airflow bridge 27a and an airflow duct 27b made in one piece, the airflow bridge 27a having two airway openings 27a' forming a portion of the inhalation channel 20 and the airflow duct 27b extending in the sonication chamber 22 from the airflow bridge 27a for providing the air flow from the surroundings to the sonication chamber.

The airflow bridge 27a cooperates with the frustoconical element 20a at the second diameter 20a2.

The airflow bridge 27a has two opposite peripheral openings 27a" providing air flow to the airflow duct 27b.

The cooperation with the airflow bridge 27a and the frustoconical element 20a is arranged so that the two opposite peripheral openings 27a" cooperate with complementary openings 20a" in the frustoconical element 20a.

The mouthpiece 1 and the frustoconical element 20a are radially spaced and an airflow chamber 28 is arranged between them.

As depicted in FIGS. 1 and 2, the mouthpiece 1 has two opposite peripheral openings 1".

The peripheral openings 27a", 20a", 1" of the airflow bridge 27a, the frustoconical element 20a and the mouthpiece 1 directly supply maximum air flow to the sonication chamber 22.

The frustoconical element 20a includes an internal passage, aligned in the similar direction as the inhalation channel 20, having a first diameter 20a1 less than that of a second diameter 20a2, such that the internal passage reduces in diameter over the frustoconical element 20a.

The frustoconical element 20a is positioned in alignment with the means of ultrasonic vibrations 5 and a capillary element 7, wherein the first diameter 20a1 is linked to an inner duct 11 of the mouthpiece 1 and the second diameter 20a2 is linked to the inner container 20b.

The inner container 20b has an inner wall delimiting the sonication chamber 22 and the liquid chamber 21.

The liquid reservoir structure 2 has an outer container 20c delimiting the outer wall of the liquid chamber 21.

The inner container 20b and the outer container 20c are respectively the inner wall and the outer wall of the liquid chamber 21.

The liquid reservoir structure 2 is arranged between the mouthpiece 1 and the casing 3 and is detachable from the mouthpiece 1 and the casing 3.

The liquid reservoir structure 2 and the mouthpiece 1 or the casing 3 may include complimentary arrangements for

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engaging with one another; further such complimentary arrangements may include one of the following: a bayonet type arrangement; a threaded engaged type arrangement; a magnetic arrangement; or a friction fit arrangement; wherein the liquid reservoir structure 2 includes a portion of the arrangement and the mouthpiece 1 or the casing 3 includes the complimentary portion of the arrangement.

In the reusable arrangement, the components are substantially the same. The differences in the reusable arrangement vis-a-vis the disposable arrangement are the accommodations made to replace the liquid reservoir structure 2.

As shown in FIG. 3, the liquid chamber 21 has a top wall 23 and a bottom wall 25 closing the inner container 20b and the outer container 20c of the liquid chamber 21.

The capillary element 7 is arranged between a first section 20b1 and a second section 20b2 of the inner container 20b.

The capillary element 7 has a flat shape extending from the sonication chamber to the liquid chamber.

As depicted in FIG. 2 or 3, the capillary element 7 comprises a central portion 7a in U-shape and a peripheral portion 7b in L-shape.

The L-shape portion 7b extends into the liquid chamber 21 on the inner container 20b and along the bottom wall 25.

The U-shape portion 7a is contained into the sonication chamber 21. The U-shape portion 7a on the inner container 20b and along the bottom wall 25.

In the ultrasonic mist inhaler, the U-shape portion 7a has an inner portion 7a1 and an outer portion 7a2, the inner portion 7a1 being in surface contact with an atomization surface 50 of the means of ultrasonic vibrations 5 and the outer portion 7a2 being not in surface contact with the means of ultrasonic vibrations 5.

The bottom wall 25 of the liquid chamber 21 is a bottom plate 25 closing the liquid chamber 21 and the sonication chamber 22. The bottom plate 25 is sealed, thus preventing leakage of liquid from the sonication chamber 22 to the casing 3.

The bottom plate 25 has an upper surface 25a having a recess 25b on which is inserted an elastic member 8. The means of ultrasonic vibrations 5 are supported by the elastic member 8. The elastic member 8 is formed from an annular plate-shaped rubber having an inner hole 8' wherein a groove is designed for maintaining the means of ultrasonic vibrations 5.

The top wall 23 of the liquid chamber 21 is a cap 23 closing the liquid chamber 23.

The top wall 23 has a top surface 23 representing the maximum level of the liquid that the liquid chamber 21 may contain and the bottom surface 25 representing the minimum level of the liquid in the liquid chamber 21.

The top wall 23 is sealed, thus preventing leakage of liquid from the liquid chamber 21 to the mouthpiece 1.

The top wall 23 and the bottom wall 25 are fixed to the liquid reservoir structure 2 by means of fixation such as screws, glue or friction.

As depicted in FIG. 3, the elastic member is in line contact with the means of ultrasonic vibrations 5 and prevents contact between the means of ultrasonic vibrations 5 and the inhaler walls, suppression of vibrations of the liquid reservoir structure are more effectively prevented. Thus, fine particles of the liquid atomized by the atomizing member can be sprayed farther.

As depicted in FIG. 3, the inner container 20b has openings 20b' between the first section 20b1 and the second section 20b2 from which the capillary element 7 is extending from the sonication chamber 21. The capillary element 7 absorbs liquid from the liquid chamber 21 through the

apertures **20b'**. The capillary element **7** is a wick. The capillary element **7** transports liquid to the sonication chamber **22** via capillary action. In some arrangements, the capillary element **7** is made of bamboo fibers. In some arrangements, the capillary element **7** may be of a thickness between 0.27 mm and 0.32 mm and have a density between 38 g/m<sup>2</sup> and 48 g/m<sup>2</sup>.

As can be seen in FIG. 3, the means of ultrasonic vibrations **5** are disposed directly below the capillary element **7**.

The means of ultrasonic vibrations **5** may be an ultrasonic transducer. For arrangement, the means of ultrasonic vibrations **5** may be a piezoelectric transducer, which may be designed in a circular plate-shape. The material of the piezoelectric transducer may be ceramic.

A variety of transducer materials can also be used for the means of ultrasonic vibrations **5**.

The end of the airflow duct **27b1** faces the means of ultrasonic vibrations **5**. The means of ultrasonic vibrations **5** are in electrical communication with electrical contactors **101a**, **101b**. It is noted that, the distal end **4b** of the integrated circuit **4** has an inner electrode and an outer electrode. The inner electrode contacts the first electrical contact **101a** which is a spring contact probe, and the outer electrode contacts the second electrical contact **101b** which is a side pin. Via the integrated circuit **4**, the first electrical contact **101a** is in electrical communication with the positive terminal of the electrical storage device **30** by way of the microprocessor, while the second electrical contact **101b** is in electrical communication with the negative terminal of the electrical storage device **30**.

The electrical contacts **101a**, **101b** crossed the bottom plate **25**. The bottom plate **25** is designed to be received inside the perimeter wall **26** of the liquid reservoir structure **2**. The bottom plate **25** rests on complementary ridges, thereby creating the liquid chamber **21** and sonication chamber **22**.

The inner container **20b** comprises a circular inner slot **20d** on which a mechanical spring is applied.

By pushing the central portion **7a1** onto the means of ultrasonic vibrations **5**, the mechanical spring **9** ensures a contact surface between them.

The liquid reservoir structure **2** and the bottom plate **25** can be made using a variety of thermoplastic materials.

When the user draws on the ultrasonic mist inhaler **100**, an air flow is drawn from the peripheral openings **1"** and penetrates the airflow chamber **28**, passes the peripheral openings **27a"** of the airflow bridge **27a** and the frustoconical element **20a** and flows down into the sonication chamber **22** via the airflow duct **27b** directly onto the capillary element **7**. At the same time, the liquid is drawn from the reservoir chamber **21** by capillarity, through the plurality of apertures **20b'**, and into the capillary element **7**. The capillary element **7** brings the liquid into contact with the means of ultrasonic vibrations **5** of the inhaler **100**. The user's draw also causes the pressure sensor to activate the integrated circuit **4**, which directs current to the means of ultrasonic vibrations **5**. Thus, when the user draws on the mouthpiece **1** of the inhaler **100**, two actions happen at the same time. Firstly, the sensor activates the integrated circuit **4**, which triggers the means of ultrasonic vibrations **5** to begin vibrating. Secondly, the draw reduces the pressure outside the reservoir chamber **21** such that flow of the liquid through the apertures **20b'** begins, which saturates the capillary element **7**. The capillary element **7** transports the liquid to the means of ultrasonic vibrations **5**, which causes bubbles to form in

a capillary channel by the means of ultrasonic vibrations **5** and mist the liquid. Then, the mist liquid is drawn by the user.

In some arrangements, the integrated circuit **4** comprises a frequency controller which is configured to control the frequency at which the means of ultrasonic vibrations **5** operates. The frequency controller comprises a processor and a memory, the memory storing executable instructions which, when executed by the processor, cause the processor to perform at least one function of the frequency controller.

As described above, in some arrangements the ultrasonic mist inhaler **100** drives the means of ultrasonic vibrations **5** with a signal having a frequency of 2.8 MHz to 3.2 MHz in order to vaporize a liquid having a liquid viscosity of 1.05 Pa·s to 1.412 Pa·s in order to produce a bubble volume of about 0.25 to 0.5 microns. However, for liquids with a different viscosity or for other applications it the means of ultrasonic vibrations **5** may be driven at a different frequency.

For each different application for a mist generation system, there is an optimum frequency or frequency range for driving the means of ultrasonic vibrations **5** in order to optimize the generation of mist. In arrangements where the means of ultrasonic vibrations **5** is a piezoelectric transducer, the optimum frequency or frequency range will depend on at least the following four parameters:

#### 1. Transducer Manufacturing Processes

In some arrangements, the means of ultrasonic vibrations **5** comprises a piezoelectric ceramic. The piezoelectric ceramic is manufactured by mixing compounds to make a ceramic dough and this mixing process may not be consistent throughout production. This inconsistency can give rise to a range of different resonant frequencies of the cured piezoelectric ceramic.

If the resonant frequency of the piezoelectric ceramic does not correspond to the required frequency of operation of the device then no mist is produced during the operation of the device. In the case of a nicotine mist inhaler, even a slight offset in the resonant frequency of the piezoelectric ceramic is enough to impact the production of mist, meaning that the device will not deliver adequate nicotine levels to the user.

#### 2. Load on Transducer

During operation, any changes in the load on the piezoelectric transducer will inhibit the overall displacement of the oscillation of the piezoelectric transducer. To achieve optimal displacement of the oscillation of the piezoelectric transducer, the drive frequency must be adjusted to enable the circuit to provide adequate power for maximum displacement.

The types of loads that can affect the oscillator's efficiency can include the amount of liquid on the transducer (dampness of the wicking material), and the spring force applied to the wicking material to keep permanent contact with the transducer. It may also include the means of electrical connection.

#### 3. Temperature

Ultrasonic oscillations of the piezoelectric transducer are partially damped by its assembly in a device. This may include the transducer being placed in a silicone/rubber ring, and the spring exerting pressure onto the wicking material that is above the transducer. This dampening of the oscillations causes rise in local temperatures on and around the transducer.

An increase in temperature affects the oscillation due to changes in the molecular behavior of the transducer. An increase in the temperature means more energy to the

molecules of the ceramic, which temporarily affects its crystalline structure. Although the effect is reversed as the temperature reduces, a modulation in supplied frequency is required to maintain optimal oscillation. This modulation of frequency cannot be achieved with a conventional fixed frequency device.

An increase in temperature also reduces the viscosity of the solution (e-liquid) which is being vaporized, which may require an alteration to the drive frequency to induce cavitation and maintain continuous mist production. In the case of a conventional fixed frequency device, a reduction in the viscosity of the liquid without any change in the drive frequency will reduce or completely stop mist production, rendering the device inoperable.

#### 4. Distance to Power Source

The oscillation frequency of the electronic circuit can change depending on the wire-lengths between the transducer and the oscillator-driver. The frequency of the electronic circuit is inversely proportional to the distance between the transducer and the remaining circuit.

Although the distance parameter is primarily fixed in a device, it can vary during the manufacturing process of the device, reducing the overall efficiency of the device. Therefore, it is desirable to modify the drive frequency of the device to compensate for the variations and optimize the efficiency of the device.

A piezoelectric transducer can be modelled as an RLC circuit in an electronic circuit, as shown in FIG. 5. The four parameters described above may be modelled as alterations to the overall inductance, capacitance, and/or resistance of the RLC circuit, changing the resonance frequency range supplied to the transducer. As the frequency of the circuit increases to around the resonance point of the transducer, the log Impedance of the overall circuit dips to a minimum and then rises to a maximum before settling to a median range.

FIG. 6 shows a generic graph explaining the change in overall impedance with increase in frequency in an RLC circuit. FIG. 7 shows how a piezoelectric transducer acts as a capacitor in a first capacitive region at frequencies below a first predetermined frequency  $f_s$ , and in a second capacitive region at frequencies above a second predetermined frequency  $f_p$ . The piezoelectric transducer acts as an inductor in an inductive region at frequencies between the first and second predetermined frequencies  $f_s$ ,  $f_p$ . In order to maintain optimal oscillation of the transducer and hence maximum efficiency, the current flowing through the transducer must be maintained at a frequency within the inductive region.

The frequency controller of the device of some arrangements is configured to maintain the frequency of oscillation of the piezoelectric transducer (the means of ultrasonic vibrations 5) within the inductive region, in order to maximize the efficiency of the device.

The frequency controller is configured to perform a sweep operation in which the frequency controller drives the transducer at frequencies which track progressively across a predetermined sweep frequency range. As the frequency controller performs the sweep, the frequency controller monitors an Analog-to-Digital Conversion (ADC) value of an Analog-to-Digital converter which is coupled to the transducer. In some arrangements the ADC value is a parameter of the ADC which is proportional to the voltage across the transducer. In other arrangements, the ADC value is a parameter of the ADC which is proportional to the current flowing through the transducer.

As will be described in more detail below, the frequency controller of some arrangements determines the active

power being used by the ultrasonic transducer by monitoring the current flowing through the transducer.

During the sweep operation, the frequency controller locates the inductive region of the frequency for the transducer. Once the frequency controller has identified the inductive region, the frequency controller records the ADC value and locks the drive frequency of the transducer at a frequency within the inductive region (i.e. between the first and second predetermined frequencies  $f_s$ ,  $f_p$ ) in order to optimize the ultrasonic cavitation by the transducer. When the drive frequency is locked within the inductive region, the electro-mechanical coupling factor of the transducer is maximized, thereby maximizing the efficiency of the device.

In some arrangements, the frequency controller is configured to perform the sweep operation to locate the inductive region each time the oscillation is started or re-started. In the arrangements, the frequency controller is configured to lock the drive frequency at a new frequency within the inductive region each time the oscillation is started and thereby compensate for any changes in the parameters that affect the efficiency of operation of the device.

In some arrangements, the frequency controller ensures optimal mist production and maximizes efficiency of medication delivery to the user. In some arrangements, the frequency controller optimizes the device and improves the efficiency and maximizes nicotine delivery to the user.

In other arrangements, the frequency controller optimizes the device and improves the efficiency of any other device which uses ultrasound. In some arrangements, the frequency controller is configured for use with ultrasound technology for therapeutic applications in order to extend the enhancement of drug release from an ultrasound-responsive drug delivery system. Having precise, optimal frequency during operation, ensures that the microbubbles, nanobubbles, nanodroplets, liposome, emulsions, micelles or any other delivery systems are highly effective.

In some arrangements, in order to ensure optimal mist generation and optimal delivery of compounds as described above, the frequency controller is configured to operate in a recursive mode. When the frequency controller operates in the recursive mode, the frequency controller runs the sweep of frequencies periodically during the operation of the device and monitors the ADC value to determine if the ADC value is above a predetermined threshold which is indicative of optimal oscillation of the transducer.

In some arrangements, the frequency controller runs the sweep operation while the device is in the process of aerosolizing liquid in case the frequency controller is able to identify a possible better frequency for the transducer. If the frequency controller identifies a better frequency, the frequency controller locks the drive frequency at the newly identified better frequency in order to maintain optimal operation of the device.

In some arrangements, the frequency controller runs the sweep of frequencies for a predetermined duration periodically during the operation of the device. In the case of the device of the arrangements described above, the predetermined duration of the sweep and the time period between sweeps are selected to optimize the functionality of the device. When implemented in an ultrasonic mist inhaler device, this will ensure an optimum delivery to a user throughout the user's inhalation.

FIG. 8 shows a flow diagram of the operation of the frequency controller of some arrangements.

The following disclosure discloses further arrangements of mist generator devices which comprise many of the same elements as the arrangements described above. Elements of

the arrangements described above may be interchanged with any of the elements of the arrangements described in the remaining part of this disclosure.

The mist generator devices described below are used with or are for use with a hookah device **202** which is also described below. In other arrangements, the hookah device **202** comprises a plurality of other mist generator devices instead of the mist generator device **201** described herein.

To ensure adequate aerosol production, the mist generator device **201** of some arrangements comprises an ultrasonic/piezoelectric transducer of exactly or substantially 16 mm diameter. This transducer is manufactured to specific capacitance and impedance values to control the frequency and power required for desired aerosol volume production.

A horizontally placed disc-shaped 16 mm diameter ultrasonic transducer would result in a large mist generator device. To minimize the size, the ultrasonic transducer of this arrangement is held vertically in the sonication chamber (the planar surface of the ultrasonic transducer is generally parallel with the flow of aerosol mist and/or generally parallel to the longitudinal length of the mist generator device). Put another way, the ultrasonic transducer is generally perpendicular to a base of the mist generator device.

Referring now to FIGS. **9** to **11** of the accompanying drawings, the mist generator device **201** comprises a mist generator housing **204** which is elongate and optionally formed from two housing portions **205**, **206** which are attached to one another. The mist generator housing **204** comprises an air inlet port **207** and a mist outlet port **208**.

In this arrangement, the mist generator housing **204** is of injection molded plastic, specifically polypropylene that is typically used for medical applications. In this arrangement, the mist generator housing **204** is of a heterophasic copolymer. More particularly a BF970MO heterophasic copolymer, which has an optimum combination of very high stiffness and high impact strength. The mist generator housing parts molded with this material exhibit good anti-static performance.

A heterophasic copolymer such as polypropylene is particularly suitable for the mist generator housing **204** since this material does not cause condensation of the aerosol as it flows from the sonication chamber **219** through the mist outlet port **208**. This plastic material can also be directly recycled easily using industrial shredding and cleaning processes.

In FIG. **10**, the mist outlet port **208** is closed by a closure element **209**. However, it is to be appreciated that when the mist inhaler device **200** is in use, the closure element **209** is removed from the mist outlet port **208**, as shown in FIG. **9**.

Referring now to FIGS. **12** and **13**, the mist generator device **200** comprises a transducer holder **210** which is held within the mist generator housing **204**. The transducer holder **210** comprises a body portion **211** which, in this arrangement, is cylindrical or generally cylindrical in shape with circular upper and lower openings **212**, **213**. The transducer holder **210** is provided with an internal channel **214** for receiving an edge of an ultrasonic transducer **215**, as shown in FIG. **13**.

The transducer holder **210** incorporates a cutaway section **216** through which an electrode **217** extends from the ultrasonic transducer **215** so that the electrode **217** may be connected electrically to an AC driver of the hookah device **202**, as described in more detail below.

Referring again to FIG. **11**, the mist generator device **201** comprises a liquid chamber **218** which is provided within the mist generator housing **204**. The liquid chamber **218** is for containing a liquid to be atomized. In some arrange-

ments, a liquid is contained in the liquid chamber **218**. In other arrangements, the liquid chamber **218** is empty initially and the liquid chamber is filled with a liquid subsequently.

A liquid (also referred to herein as an e-liquid) composition suitable for use in an ultrasonic mist generator device **201** of some arrangements consists of a nicotine salt consisting of nicotine levulinate wherein:

The relative amount of vegetable glycerin in the composition is: from 55 to 80% (w/w), or from 60 to 80% (w/w), or from 65 to 75% (w/w), or 70% (w/w); and/or,

The relative amount of propylene glycol in the composition is: from 5 to 30% (w/w), or from 10 to 30% (w/w), or from 15 to 25% (w/w), or 20% (w/w); and/or,

The relative amount of water in the composition is: from 5 to 15% (w/w), or from 7 to 12% (w/w), or 10% (w/w); and/or,

The amount of nicotine and/or nicotine salt in the composition is: from 0.1 to 80 mg/ml, or from 0.1 to 50 mg/ml, or from 1 to 25 mg/ml, or from 10 to 20 mg/ml, or 17 mg/ml.

In some arrangements, the mist generator device **201** contains an e-liquid having a kinematic viscosity between 1.05 Pa·s and 1.412 Pa·s.

In some arrangements, the liquid chamber **218** contains a liquid comprising a nicotine levulinate salt at a 1:1 molar ratio.

In some arrangements, the liquid chamber **218** contains an e-liquid comprising nicotine, propylene glycol, vegetable glycerin, water and flavorings. In some examples, the % concentration of each component in the e-liquid is shown below in Table 1, Table 2, Table 3 or Table 4.

TABLE 1

The % concentration of each component in the e-liquid (e-liquid 1).	
Component	% (w/w)
Propylene glycol	15.1
Vegetable glycerin	70
Water	10
Nicotine	1.7
Levulinic acid	0.2
Flavorings	3

TABLE 2

The % concentration of each component in the e-liquid (e-liquid 2). (Approximately, 2:1 molar ratio of levulinic acid to nicotine.)	
Component	% (w/w)
Propylene glycol	12.87
Vegetable glycerin	70
Water	10
Nicotine	1.7
Levulinic acid	2.43
Flavorings	3



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TABLE 3

The % concentration of each component in the e-liquid (e-liquid 3). (Approximately, 1:1 molar ratio of levulinic acid to nicotine.)	
Component	% (w/w)
Propylene glycol	14.08
Vegetable glycerin	70
Water	10
Nicotine	1.7
Levulinic acid	1.22
Flavorings	3

TABLE 4

The % concentration of each component in the e-liquid (e-liquid 4). (Approximately, 3:1 molar ratio of levulinic acid to nicotine.)	
Component	% (w/w)
Propylene glycol	11.64
Vegetable glycerin	70
Water	10
Nicotine	1.7
Levulinic acid	3.66
Flavorings	3

In the non-limiting examples, the nicotine in solution is all or part in the form of nicotine levulinate.

The nicotine levulinate salt is formed by combining nicotine and levulinic acid in solution. This results in the formation of the salt nicotine levulinate, which comprises a levulinate anion and a nicotine cation.

The % concentration of nicotine in the e-liquid shown in Table 1, Table 2, Table 3 and Table 4 is approximately equivalent to 17 mg/ml.

In some arrangements, the liquid chamber **218** contains a liquid having a kinematic viscosity between 1.05 Pa·s and 1.412 Pa·s and a liquid density between 1.1 g/ml and 1.3 g/ml.

In some arrangements, the liquid within the liquid chamber **218** comprises a flavoring (e.g. a fruit flavor) which is tasted by a user when the user inhales mist generated by the hookah device.

By using an e-liquid with the correct parameters of viscosity, density and having a desired target bubble volume of liquid spray into the air, it has been found that the frequency range of 2.8 MHz to 3.2 MHz for liquid viscosity range of 1.05 Pa·s and 1.412 Pa·s and density of approximately 1.1-1.3 g/mL produce a droplet volume where 90% of droplets are below 1 micron and 50% of those are less than 0.5 microns.

The mist generator device **201** comprises a sonication chamber **219** which is provided within the mist generator housing **204**.

Returning to FIGS. **12** and **13**, the transducer holder **210** comprises a divider portion **220** which provides a barrier between the liquid chamber **218** and the sonication chamber **219**. The barrier provided by the divider portion **220** minimizes the risk of the sonication chamber **219** being flooded with liquid from the liquid chamber **218** or for a capillary element over the ultrasonic transducer **215** becoming oversaturated, either of which would overload and reduce the efficiency of the ultrasonic transducer **215**. Moreover, flooding the sonication chamber **219** or over saturating

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the capillary element could also cause an unpleasant experience with the liquid being sucked in by the user during inhalation. To mitigate this risk, the divider portion **220** of the transducer holder **210** sits as a wall between the sonication chamber **219** and the liquid chamber **218**.

The divider portion **220** comprises a capillary aperture **221** which is the only means by which liquid can flow from the liquid chamber **218** to the sonication chamber **219**, via a capillary element. In this arrangement, the capillary aperture **221** is an elongate slot having a width of 0.2 mm to 0.4 mm. The dimensions of the capillary aperture **221** are such that the edges of the capillary aperture **221** provide a biasing force which acts on a capillary element extending through the capillary aperture **221** for added control of liquid flow to the sonication chamber **219**.

In this arrangement, the transducer holder **210** is of liquid silicone rubber (LSR). In this arrangement, the liquid silicone rubber has a Shore A 60 hardness. This LSR material ensures that the ultrasonic transducer **215** vibrates without the transducer holder **210** dampening the vibrations. In this arrangement, the vibratory displacement of the ultrasonic transducer **215** is 2-5 nanometers and any dampening effect may reduce the efficiency of the ultrasonic transducer **215**. Hence, this LSR material and hardness is selected for optimal performance with minimal compromise.

Referring now to FIGS. **14** and **15**, the mist generator device **201** comprises a capillary or capillary element **222** for transferring a liquid (containing a drug or other substance) from the liquid chamber **218** to the sonication chamber **219**. The capillary element **222** is planar or generally planar with a first portion **223** and a second portion **224**. In this arrangement, the first portion **223** has a rectangular or generally rectangular shape and the second portion **224** has a partly circular shape.

In this arrangement, the capillary element **222** comprises a third portion **225** and a fourth portion **226** which are respectively identical in shape to the first and second portions **223**, **224**. The capillary element **222** of this arrangement is folded about a fold line **227** such that the first and second portions **223**, **224** and the third and fourth portions **225**, **226** are superimposed on one another, as shown in FIG. **15**.

In this arrangement, the capillary element has a thickness of approximately 0.28 mm. When the capillary element **222** is folded to have two layers, as shown in FIG. **15**, the overall thickness of the capillary element is approximately 0.56 mm. This double layer also ensures that there is always sufficient liquid on the ultrasonic transducer **215** for optimal aerosol production.

In this arrangement, when the capillary element **222** is folded, the lower end of the first and third parts **223**, **225** defines an enlarged lower end **228** which increases the surface area of the capillary element **222** in the portion of the capillary element **222** which sits in liquid within the liquid chamber **218** to maximize the rate at which the capillary element **222** absorbs liquid.

In this arrangement, the capillary element **222** is 100% bamboo fiber. In other arrangements, the capillary element is of at least 75% bamboo fiber. The benefits of using bamboo fiber as the capillary element are as described above.

Referring now to FIGS. **16** and **17**, the capillary element **222** is retained by the transducer holder **210** such that the transducer holder **210** retains the second portion **224** of the capillary element **222** superimposed on part of an atomization surface of the ultrasonic transducer **215**. In this arrangement, the circular second portion **224** sits within the inner recess **214** of the transducer holder **210**.

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The first portion **223** of the capillary element **222** extends through the capillary aperture **221** in the transducer holder **210**.

Referring now to FIGS. **18** to **20**, the second portion **206** of the mist generator housing **204** comprises a generally circular wall **229** which receives the transducer holder **222** and forms part of the wall of the sonication chamber **219**.

Contact apertures **230** and **231** are provided in a side wall of the second portion **206** for receiving electrical contacts **232** and **233** which form electrical connections with the electrodes of the ultrasonic transducer **215**.

In this arrangement, an absorbent tip or absorbent element **234** is provided adjacent the mist outlet port **208** to absorb liquid at the mist outlet port **208**. In this arrangement, the absorbent element **234** is of bamboo fiber.

Referring now to FIGS. **21** to **23**, the first portion **205** of the mist generator housing **204** is of a similar shape to the second portion **206** and comprises a further generally circular wall portion **235** which forms a further portion of the wall of the sonication chamber **219** and retains the transducer holder **210**.

In this arrangement, a further absorbent element **236** is provided adjacent the mist outlet port **208** to absorb liquid at the mist outlet port **208**.

In this arrangement, the first portion **205** of the mist generator housing **204** comprises a spring support arrangement **237** which supports the lower end of a retainer spring **238**, as shown in FIG. **24**.

An upper end of the retainer spring **238** contacts the second portion **224** of the capillary element **222** such that the retainer spring **238** provides a biasing force which biases the capillary element **222** against the atomization surface of the ultrasonic transducer **215**.

Referring to FIG. **25**, the transducer holder **210** is shown in position and being retained by the second portion **206** of the mist generator housing **204**, prior to the two portions **205**, **206** of the mist generator housing **204** being attached to one another.

Referring to FIGS. **26** to **29**, in this arrangement, the mist generator device **201** comprises an identification arrangement **239**. The identification arrangement **239** comprises a printed circuit board **240** having electrical contacts **241** provided on one side and an integrated circuit **242** and another optional component **243** provided on the other side.

The integrated circuit **242** has a memory which stores a unique identifier for the mist generator device **201**. The electrical contacts **241** provide an electronic interface for communication with the integrated circuit **242**.

The printed circuit board **240** is, in this arrangement, mounted within a recess **244** on one side of the mist generator housing **204**. The integrated circuit **242** and optional other electronic components **243** sit within a further recess **245** so that the printed circuit board **240** is generally flush with the side of the mist generator housing **204**.

In this arrangement, the integrated circuit **242** is a one-time-programmable (OTP) device which provides an anti-counterfeiting feature that allows only genuine mist generator devices from the manufacturer to be used with the device. This anti-counterfeiting feature is implemented in the mist generator device **201** as a specific custom integrated circuit (IC) that is bonded (with the printed circuit board **240**) to the mist generator device **201**. The OTP as IC contains a truly unique information that allows a complete traceability of the mist generator device **201** (and its content) over its lifetime as well as a precise monitoring of the

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consumption by the user. The OTP IC allows the mist generator device **201** to function to generate mist only when authorized.

The OTP, as a feature, dictates the authorized status of a specific mist generator device **201**. Indeed, in order to prevent emissions of carbonyls and keep the aerosol at safe standards, experiments have shown that the mist generator device **201** is considered empty of liquid in the liquid chamber **218** after approximately 1,000 seconds of aerosolization. In that way a mist generator device **201** that is not genuine or empty will not be able to be activated after this predetermined duration of use.

The OTP, as a feature, may be part of a complete chain with the conjunction of the digital sale point, the mobile companion application and the mist generator device **201**. Only a genuine mist generator device **201** manufactured by a trusted party and sold on the digital sale point can be used in the hookah device **202** described below in connection with FIGS. **33-43**. The OTP IC is read by the hookah device **202** which recognizes the mist generator device **201**.

In some arrangements, the OTP IC is disposable in the same way as the mist generator device **201**. Whenever the mist generator device **201** is considered empty, it will not be activated if inserted into a hookah device **202**. Similarly, a counterfeit mist generator device **201** would not be functional in the hookah device **202**.

FIGS. **30** to **32** illustrate how air flows through the mist generator device **201** during operation.

The sonication of the liquid drug (e.g. nicotine) transforms it into mist (aerosolization). However, this mist would settle over the ultrasonic transducer **215** unless enough ambient air is available to replace the rising aerosol. In the sonication chamber **219**, there is a requirement for a continuous supply of air as mist (aerosol) is generated and pulled out through the mist outlet port **208**. To cater to this requirement, an airflow channel is provided. In this arrangement the airflow channel has an average cross-sectional area of 11.5 mm<sup>2</sup>, which is calculated and designed into the sonication chamber **219** based on the negative air pressure from an average user. This also controls the mist-to-air ratio of the inhaled aerosol, controlling the amount of drug delivered to the user.

Based on design requirements, the air flow channel is routed such that it initiates from the bottom of the sonication chamber **219**. The opening at the bottom of the aerosol chamber aligns with and is tightly adjacent to the opening to an airflow bridge in the device. The air flow channel runs vertically upwards along the reservoir and continues until the center of the sonication chamber (concentric with the ultrasonic transducer **215**). Here, it turns 90° inwards. The flow path then continues on until approximately 1.5 mm from the ultrasonic transducer **215**. This routing ensures maximized ambient air supplied directly in the direction of the atomization surface of the ultrasonic transducer **215**. The airflows through the channel, towards the transducer, collects the generated mist as it travels out through the mist outlet port **208**.

Referring now to FIGS. **33** and **34** of the accompanying drawings, a hookah device **202** of some arrangements is configured to releasably attach to an existing hookah **246**. The hookah device **202** attaches to the stem **247** in place of a conventional hookah head which would otherwise house the tobacco and the charcoal (or electronic heating element).

The hookah **246** comprises a water chamber and an elongate stem **247** having a first end which is attached to the water chamber. The stem **247** comprises a mist flow path

which extends from a second end of the stem 247, through the stem 247, to the first end and into the water chamber.

In this arrangement, the hookah device 202 is releasably attached to the second end of the stem 247 of the hookah 246. However, in other arrangements the hookah device 202 is not designed to be removable and is instead fixed to or formed integrally with the stem 247 of the hookah 246.

Referring to FIGS. 33-43 of the accompanying drawings, the hookah device 202 comprises a housing 248 which incorporates a base 249 and a cover 250 which are attached or releasably attached to one another. In this arrangement, the housing 248 is cylindrical and generally disk-shaped.

In this arrangement, the cover 250 is provided with a plurality of air inlets 251 to allow air to be drawn into the hookah device 202. The base 249 is provided with a hookah outlet port 252 to allow air and mist to flow out from the hookah device 202 and into the hookah 246. The diameter of the hookah outlet port 252 is sufficient to allow a user to draw air quickly through the hookah device 202 and through the hookah 246 to generate bubbles of mist which travel through the water in the hookah 246.

In this arrangement, the hookah outlet port 252 is a circular aperture which receives the end of the stem 247 of the hookah 246. The hookah device 202 is supported on the stem 247 of the hookah 246 with a generally gas-tight seal being formed between the hookah device 202 and the stem 247.

In this arrangement, the hookah device 202 is a self-contained device with the electronic components and mist generator devices containing e-liquid being housed within the housing 248.

In this arrangement, the hookah device 202 comprises an upper support plate 253, a middle support plate 254 and a lower support plate 255 which are stacked on top of one another. The support plates 253-255 support a plurality of mist generator devices 201 within the hookah device 202. Each mist generator device is a mist generator device 201 as described in this disclosure. In this arrangement, the mist generator devices 201 are releasably attached to the hookah device 202 so that the mist generator devices 201 can be replaced when empty (i.e. when the e-liquid is partially or completely depleted).

In this arrangement, the hookah device 202 comprises four mist generator devices 201 which are controlled by the controller of the hookah device 202. In other arrangements, the hookah device 202 comprises a plurality of mist generator devices 201, such as at least two mist generator devices 201.

The hookah device 202 is provided with first contact terminals 259 which establish and electrical connection between the controller of the hookah device 202 and the electrical contacts 232 and 233 of each mist generator device 201. The hookah device 202 is provided with second contact terminals 260 which establish and electrical connection between the controller of the hookah device 202 and the electrical contacts 241 on the OTP PCB of each mist generator device 201.

In this arrangement, the hookah device 202 comprises an upper printed circuit board (PCB) 256 which is positioned on top of the upper support plate 253 and a middle PCB 257 which is positioned between the middle support plate 254 and the lower support plate 255. A lower PCB 258 is positioned beneath the lower support plate 255. The PCBs 256-258 carry the electronic components which make up a driver device of the hookah device 202. The PCBs 256-258

are coupled electrically to one another to allow the electronic components on each PCB 256-258 to communicate with one another.

While there are three PCBs 256-258 in this arrangement, other arrangements comprise only one PCB or a plurality of PCBs which perform the same functions of the driver device of the hookah device 202.

In this arrangement, the hookah device 202 comprises a plurality of magnets 261 which enable the support plates 253-255 to be releasably attached to one another. Once the hookah device 202 is assembled with the support plates 253-255 and the PCBs 256-258 stacked on top of one another with the mist generator device 201 retained between the support plates 253-255, the cover 250 is placed onto the base 249 and a plurality of screws 262 are used to releasably attach the cover 250 to the base 249.

The upper support plate 253 comprises a manifold 263 which is positioned centrally on one side of the upper support plate 253. In this arrangement, the manifold 263 is provided with four apertures 264 (only one of which is visible in FIG. 40) which each receive the outlet port 208 of a respective mist generator device 201. In this arrangement, the hookah device 202 comprises four mist generator devices 201 which are releasably coupled to the manifold at 90° relative to one another. In other arrangements, the manifold 263 comprises a different number of apertures 264 to correspond with the number of mist generator devices 201 being used with the hookah device 202.

The manifold 263 comprises a manifold pipe 265 which is in fluid communication with the apertures 264 such that mist generated by the mist generator devices 201 can combine and flow down from the manifold 263 and out of the manifold pipe 265. When the hookah device 202 is assembled, the manifold pipe 265 extends through an aperture 266 in the middle support plate 254 and an aperture 267 in the middle PCB 257. The manifold pipe 265 then connects to an outlet pipe 268 which extends through the lower support plate 255 to provide a fluid flow path through the lower support plate to the hookah outlet port 252 of the hookah device 202.

The outlet pipe 268 extends downwardly from the underside of the lower support plate 255 and through an aperture 269 in the lower PCB 258. The outlet pipe 268 then extends through an aperture 270 in the base 249 of the hookah device 202. In this arrangement, the outlet pipe 268 and the hookah outlet port 252 are a hookah attachment arrangement 271 which attaches or is configured to attach the hookah device 202 to a hookah 246. In this arrangement, the hookah device 202 is attached to the hookah 246 by inserting part of the stem 247 of the hookah into the hookah outlet port 252.

The hookah outlet port 252 provides a fluid flow path 272, as shown in FIGS. 42 and 43, from the mist outlet ports 208 of the mist generator devices 201 and out of the hookah device 202 such that mist generated by the mist generator devices 201 flows out from the hookah device 202 and into the hookah 246. The mixture of air and mist creates bubbles in the water of the hookah 246. The bubbles escape the water surface with the mist rising above the surface of water in the water bowl of the hookah and travel through the pipe to the user during inhalation.

In this arrangement, the upper PCB 256 carries a pressure sensor which senses the pressure of air in the vicinity of the mist outlet ports 208 of the mist generator devices 201. The pressure sensor thereby detects a negative pressure in the vicinity of the mist outlet ports 208 when a user draws on the hookah and sucks air through the mist generator devices 201 along the fluid flow path 272. The pressure sensor provides

a signal to the controller of the hookah device, as described below, for the controller to activate at least one of the mist generator devices **201** to generate mist as the user draws on the hookah.

In this arrangement, the lower PCB **258** carries power control components **273** which control and distribute power to the other electronic components of the hookah device **202**. In some arrangements, the power control components **273** receive power from an external power source, such as a mains power adapter, which is releasably attached to the hookah device **202**. In this arrangement, the hookah head **202** is configured to be powered by an external power adaptor at a DC voltage in the range 20V to 40V.

In other arrangements, the hookah device **202** comprises a battery which is integrated within the hookah device **202** and connected to the power control components **273**. In some arrangements, the battery is a rechargeable Li—Po battery. In some arrangements, the battery is configured to output a 20V to 40V DC voltage. In some arrangements, the battery has a high discharge rate. The high discharge rate is necessary for the voltage amplification that is required by the ultrasonic transducers of the mist generator devices **201**. Due to the requirement of having a high discharge rate, the Li—Po battery of some arrangements is designed specifically for continuous current draw. In some arrangements, a charging port is provided on the hookah device **202** to enable the battery to be charged by an external power source.

The middle PCB **257** incorporates a processor **274** and a memory **275** of a controller or computing device of the hookah device **202**. In this arrangement, the processor **274** and the memory **275** are components of the driver device within the hookah device **202**. In this arrangement, the functionality of the driver device is implemented in executable instructions which are stored in the memory **275** which, when executed by the processor **274**, cause the processor **274** to control the driver device to perform at least one function. The driver device is connected electrically to each of the mist generator devices **201**. In this arrangement, the driver device of the hookah device **202** is coupled for communication with each mist generator device **201** by a data bus, such as an PC data bus. In this arrangement, each mist generator device **201** is identified by a unique identifier which is used when controlling the mist generator device **201** via the data bus. In some arrangements, the unique identifier is stored in the OTPIC of the mist generator device **201**.

In some arrangements, the driver device controls each respective mist generator device independently. In some arrangements, the control functionality is implemented in executable instructions stored in the memory **275**. The independent control configuration enables the driver device to activate or deactivate each mist generator device **201** independently of the other mist generator devices **201**. The driver device can therefore control one or more of the mist generator devices **201** to generate mist simultaneously or alternately according to predetermined requirements.

In some arrangements, the driver device controls the mist generator devices **201** to activate and/or deactivate successively in sequence. In some arrangements the sequence of activation of the mist generator devices **201** optimizes the operation of the hookah device **202** by ensuring that mist is generated sufficiently quickly to allow the mist to pass in bubbles through the water in the water chamber of the hookah. The hookah device **202** of some arrangements thereby enables bubbles of mist to be drawn at high velocity through the water in the water chamber as a user draws on the hookah mouthpiece. Consequently, water soluble com-

pounds (e.g. vegetable glycerin, flavorings, etc.) are able to travel through the water in the bubbles of mist for inhalation by a user.

In some arrangements, the driver device controls the mist generator devices **201** to activate for a predetermined length of time one after another in sequence. In some arrangements, the driver device controls the mist generator devices **201** to activate in rotation such that the mist generator devices **201** are activated one after the other and/or one at a time in a clockwise or anticlockwise direction.

In some arrangements, the driver device controls the mist generator devices **201** to activate in pairs. In some arrangements, the driver device controls two mist generator devices **201** to activate simultaneously; either two mist generator devices **201** that are adjacent to one another or two mist generator devices that are opposite one another.

In some arrangements, the driver device is configured to ensure that a mist generator device **201** is not activated if it is not properly wicked with e-liquid in its capillary **222** or if the liquid chamber **218** empty or nearly empty of e-liquid. This provides protection for the hookah device **202** by ensuring that the hookah device **202** maintains correct operation.

The electronics of the driver device of the hookah device **202** (distributed across the PCBs **256-258**) are divided as discussed below. The following description refers to the control of one mist generator device **201** but it is to be appreciated that the driver device of the hookah device **202** controls each mist generator device **201** independently in the same way.

In order to obtain the most efficient aerosolization, with particle size below 1  $\mu\text{m}$ , the driver device provides the contacts pads receiving the ultrasonic transducer **215** (piezoelectrical ceramic disc (PZT)) with high adaptive frequency (approximately 3 MHz).

This section not only has to provide high frequency but also protect the ultrasonic transducer **215** against failures while providing constant optimized cavitation.

PZT mechanical deformation is linked to the AC Voltage amplitude that is applied to it, and in order to guarantee optimal functioning and delivery of the system at every sonication, the maximum deformation must be supplied to the PZT all the time.

However, in order to prevent the failure of the PZT, the active power transferred to it must be precisely controlled.

The processor **274** and the memory **275** are configured to control modulation of the active power given to the PZT at every instant without compromising the mechanical amplitude of vibration of the PZT.

By Pulse Width Modulation (PWM) of the AC voltage applied to the PZT, the mechanical amplitude of the vibration remains the same.

Indeed, the RMS voltage applied would be the same with effective Duty Cycle modulation as with Voltage modulation, but the active power transferred to the PZT would degrade. Indeed, given the formula below:

Active Power displayed to the PZT being

$$P_a = \frac{2\sqrt{2}}{\pi} I_{rms} * V_{rms} * \cos \varphi,$$

Where

$\varphi$  is the shift in phase between current and voltage

$I_{rms}$  is the root mean square Current

$V_{rms}$  is the root mean square Voltage.

When considering the first harmonic, Irms is a function of the real voltage amplitude applied to the transducer, as the pulse width modulation alters the duration of voltage supplied to the transducer, controlling Irms.

The specific design of the PMIC uses a state-of-the-art design, enabling ultra-precise control of the frequency range and steps to apply to the PZT including a complete set of feedback loops and monitoring path for the control section to use.

In this arrangement, the driver device comprises a DC/DC boost converter and transformer that carry the necessary power to the PZT contact pads.

In this arrangement, the driver device comprises an AC driver for converting a voltage from the battery into an AC drive signal at a predetermined frequency to drive the ultrasonic transducer.

The driver device comprises an active power monitoring arrangement for monitoring the active power used by the ultrasonic transducer (as described above) when the ultrasonic transducer is driven by the AC drive signal. The active power monitoring arrangement provides a monitoring signal which is indicative of an active power used by the ultrasonic transducer.

The processor **274** within the driver device controls the AC driver and receives the monitoring signal drive from the active power monitoring arrangement.

The memory **275** of driver device stores instructions which, when executed by the processor, cause the processor to:

- A. control the AC driver to output an AC drive signal to the ultrasonic transducer at a predetermined sweep frequency;
- B. calculate the active power being used by the ultrasonic transducer based on the monitoring signal;
- C. control the AC driver to modulate the AC drive signal to maximize the active power being used by the ultrasonic transducer;
- D. store a record in the memory of the maximum active power used by the ultrasonic transducer and the sweep frequency of the AC drive signal;
- E. repeat steps A-D for a predetermined number of iterations with the sweep frequency incrementing with each iteration such that, after the predetermined number of iterations has occurred, the sweep frequency has been incremented from a start sweep frequency to an end sweep frequency;
- F. identify from the records stored in the memory the optimum frequency for the AC drive signal which is the sweep frequency of the AC drive signal at which a maximum active power is used by the ultrasonic transducer; and
- G. control the AC driver to output an AC drive signal to the ultrasonic transducer at the optimum frequency to drive the ultrasonic transducer to atomize a liquid.

In some arrangements, the active power monitoring arrangement comprises a current sensing arrangement for sensing a drive current of the AC drive signal driving the ultrasonic transducer, wherein the active power monitoring arrangement provides a monitoring signal which is indicative of the sensed drive current.

In some arrangements, the current sensing arrangement comprises an Analog-to-Digital Converter which converts the sensed drive current into a digital signal for processing by the processor.

In some arrangements, the memory stores instructions which, when executed by the processor, cause the processor to: repeat steps A-D above with the sweep frequency being

incremented from a start sweep frequency of 2900 kHz to an end sweep frequency of 2960 kHz.

In some arrangements, the memory stores instructions which, when executed by the processor, cause the processor to: repeat steps A-D above with the sweep frequency being incremented from a start sweep frequency of 2900 kHz to an end sweep frequency of 3100 kHz.

In some arrangements, the memory stores instructions which, when executed by the processor, cause the processor to: in step G, control the AC driver to output an AC drive signal to the ultrasonic transducer at frequency which is shifted by a predetermined shift amount from the optimum frequency.

In some arrangements, the predetermined shift amount is between 1-10% of the optimum frequency.

The pressure sensor used in the device serves two purposes. The first purpose is to prevent unwanted and accidental start of the sonic engine (driving the ultrasonic transducer). This functionality is implemented in the processing arrangement of the device, but optimized for low power, to constantly measure environmental parameters such as temperature and ambient pressure with internal compensation and reference setting in order to accurately detect and categories what is called a true inhalation.

The second purpose of the pressure sensor is to be able to monitor not only the exact duration of the inhalations by the user for precise inhalation volume measurement, but also to be able to determine the strength of the user inhalation. All in all, we are able to completely draw the pressure profile of every inhalation and anticipate the end of an inhalation for aerosolization optimization.

In some arrangements, the hookah device **202** comprises a Bluetooth™ Low Energy (BLE) microcontroller. Indeed, this enables the setting to provide extremely accurate inhalation times, optimized aerosolization, monitor numerous parameters to guarantee safe misting and prevent the use of non-genuine e-liquids or aerosol chambers and protect both the device against over-heating risks and the user against over-misting in one shot.

The use of the BLE microcontroller allows over-the-air update to continuously provide improved software to users based on anonymized data collection and trained AI for PZT modelling.

The hookah device **202** is a precise, reliable and a safe aerosolization solution for daily customer usage and, as such, must provide a controlled and trusted aerosolization.

This is performed through an internal method that can be broken apart into several sections as follows:

Sonication

In order to provide the most optimal aerosolization the ultrasonic transducer (PZT) or each mist generator device **201** needs to vibrate in the most efficient way.

Frequency

The electromechanical properties of piezoelectrical ceramics state that the component has the most efficiency at the resonant frequency. But also, vibrating a PZT at resonance for a long duration will inevitably end with the failure and breaking of the component which renders the aerosol chamber unusable.

Another important point to consider when using piezoelectrical materials is the inherent variability during manufacturing and its variability over temperature and lifetime.

Resonating a PZT at 3 MHz in order to create droplets of a size < 1 um requires an adaptive method in order to locate and target the 'sweet spot' of the particular PZT inside every aerosol chamber used with the device for every single inhalation.

## Sweep

Because the device has to locate the ‘sweet spot’ for every single inhalation and because of over-usage, the PZT temperature varies as the device uses an in-house double sweep method.

The first sweep is used when the device has not been used with a particular aerosol chamber for a time that is considered enough for all the thermal dissipation to occur and for the PZT to cool down to ‘default temperature’. This procedure is also called a cold start. During this procedure the PZT needs a boost in order to produce the required aerosol. This is achieved by only going over a small subset of Frequencies between 2900 kHz to 2960 kHz which, considering extensive studies and experiments, covers the resonant point.

For each frequency in this range, the sonic engine is activated and the current going through the PZT is actively monitored and stored by the microcontroller via an Analog-to-Digital Converter (ADC), and converted back to current in order to be able to precisely deduct the Power used by the PZT.

This yields the cold profile of this PZT regarding frequency and the Frequency used throughout the inhalation is the one that uses the most current, meaning the lowest impedance Frequency.

The second sweep is performed during any subsequent inhalation and cover the entire range of frequencies between 2900 kHz to 3100 kHz due to the modification of the PZT profile with regards to temperature and deformation. This hot profile is used to determine the shift to apply.

## Shift

Because the aerosolization must be optimal, the shift is not used during any cold inhalation and the PZT will hence vibrate at resonant frequency. This can only happen for a short and unrepeated duration of time otherwise the PZT would inevitably break.

The shift however is used during most of inhalations as a way to still target a low impedance frequency, thus resulting in quasi-optimal operation of the PZT while protecting it against failures.

Because the hot and cold profiles are stored during inhalation the microcontroller can then select the proper shifted frequency according to the measured values of current through the PZT during sweep and ensure a safe mechanical operation.

The selection of the direction to shift is crucial as the piezoelectrical component behaves in a different way if outside the duplet resonant/anti-resonant frequency or inside this range. The selected shift should always be in this range defined by Resonant to anti-Resonant frequencies as the PZT is inductive and not capacitive.

Finally, the percentage to shift is maintained below 10% in order to still remain close to the lowest impedance but far enough of the resonance.

## Adjustment

Because of the intrinsic nature of PZTs, every inhalation is different. Numerous parameters other than the piezoelectrical element influence the outcome of the inhalation, like the amount of e-liquid remaining inside the aerosol chamber, the wicking state of the gauze or the battery level of the device.

As of this, the device permanently monitors the current used by the PZT inside the aerosol chamber and the microcontroller constantly adjusts the parameters such as the frequency and the Duty Cycle in order to provide the aerosol chamber with the most stable power possible within a

pre-defined range that follows the studies and experimental results for most optimal safe aerosolization.

## Battery Monitoring

In some arrangements, a battery is integrated within the hookah device **202**. In these arrangements, the hookah device **202** is powered by a DC Li—Po battery which provides a required voltage to the hookah device **202**. Due to the requirement of having a high discharge rate, the Li—Po battery of some arrangement is designed specifically for continuous current draw.

Because the battery voltage drops and varies a lot when activating the sonication section, the microcontroller constantly monitors the power used by the PZT inside the aerosol chamber to ensure a proper but also safe aerosolization.

And because the key to aerosolization is control, the device ensures first that the Control and Information section of the device always function and does not stop in the detriment of the sonication section.

This is why the adjustment method also takes into great account the real time battery level and, if need be, modifies the parameters like the Duty Cycle to maintain the battery at a safe level, and in the case of a low battery before starting the sonic engine, the Control and Information section will prevent the activation.

## Power Control

As being said, the key to aerosolization is control and the method used in the device is a real time multi-dimensional function that takes into account the profile of the PZT, the current inside the PZT and the battery level of the device at all time.

All this is only achievable thanks to the use of a microcontroller that can monitor and control every element of the device to produce an optimal inhalation.

## Interval

Because the device relies on a piezoelectrical component, the device prevents the activation of the sonication section if an inhalation stops. The safety delay in between two inhalations is adaptive depending on the duration of the previous one. This allows the gauze to wick properly before the next activation.

With this functioning, the device can safely operate and the aerosolization is rendered more optimal with no risk of breaking the PZT element nor exposing the user to toxic components.

## Connectivity (BLE)

The device Control and Information section is composed of a wireless communication system in the form of a Bluetooth Low Energy capable microcontroller. The wireless communication system is in communication with the processor of the device and is configured to transmit and receive data between the driver device and a computing device, such as a smartphone.

The connectivity via Bluetooth Low Energy to a companion mobile application ensures that only small power for this communication is required thus allowing the device to remain functioning for a longer period of time if not used at all, compared to traditional wireless connectivity solutions like Wi-Fi, classic Bluetooth, GSM or even LTE-M and NB-IOT.

Most importantly, this connectivity is what enables the OTP as a feature and the complete control and safety of the inhalations. Every data from resonant frequency of an inhalation to the one used, or the negative pressure created by the user and the duration are stored and transferred over BLE for further analysis and improvements of the embedded software.

Finally, this connectivity enables the update of the embedded firmware inside the device and over the air (OTA), which guarantees that the latest versions can always be deployed rapidly. This gives great scalability to the device and insurance that the device is intended to be maintained.

Because the aerosolization of the e-liquid is achieved via the mechanical action of the piezoelectric disc and not due to the direct heating of the liquid, the individual components of the e-liquid (propylene glycol, vegetable glycerin, flavoring components, etc.) remain largely in-tact and are not broken into smaller, harmful components such as acrolein, acetaldehyde, formaldehyde, etc. at the high rate seen in traditional ENDS.

All of the above applications involving ultrasonic technology can benefit from the optimization achieved by the frequency controller which optimizes the frequency of sonication for optimal performance.

It is to be appreciated that the disclosures herein are not limited to use for nicotine delivery. The devices disclosed herein are for use with any drugs or other compounds (e.g. CBD), with the drug or compound being provided in a liquid within the liquid chamber of the device for aerosolization by the device.

The hookah device **202** of some arrangements is a healthier alternative to conventional hookah heads which burn tobacco using heat from charcoal or an electrical element. Nevertheless, the hookah device **202** of some arrangements still provides the same user experience as a conventional hookah due to the mist bubbles in the water of the hookah. Users are therefore likely to want to use the ultrasonic hookah device **202** of some arrangements instead of a conventional tobacco-burning hookah and thereby avoid the dangers of smoking tobacco in a hookah.

The foregoing outlines features of several arrangements, examples or embodiments so that those of ordinary skill in the art may better understand various aspects of the present disclosure. Those of ordinary skill in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of various examples or embodiments introduced herein. Those of ordinary skill in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Although the subject matter has been described in language specific to structural features or methodological acts, it is to be understood that the subject matter of the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing at least some of the claims.

Various operations of examples or embodiments are provided herein. The order in which some or all of the operations are described should not be construed to imply that these operations are necessarily order dependent. Alternative ordering will be appreciated having the benefit of this description. Further, it will be understood that not all operations are necessarily present in each embodiment provided herein. Also, it will be understood that not all operations are necessary in some examples or embodiments.

Moreover, “exemplary” is used herein to mean serving as an example, instance, illustration, etc., and not necessarily as advantageous. As used in this application, “or” is intended to mean an inclusive “or” rather than an exclusive “or”. In

addition, “a” and “an” as used in this application and the appended claims are generally be construed to mean “one or more” unless specified otherwise or clear from context to be directed to a singular form. Also, at least one of A and B and/or the like generally means A or B or both A and B. Furthermore, to the extent that “includes”, “having”, “has”, “with”, or variants thereof are used, such terms are intended to be inclusive in a manner similar to the term “comprising”. Also, unless specified otherwise, “first,” “second,” or the like are not intended to imply a temporal aspect, a spatial aspect, an ordering, etc. Rather, such terms are merely used as identifiers, names, etc. for features, elements, items, etc. For example, a first element and a second element generally correspond to element A and element B or two different or two identical elements or the same element.

Also, although the disclosure has been shown and described with respect to one or more implementations, equivalent alterations and modifications will occur to others of ordinary skill in the art based upon a reading and understanding of this specification and the annexed drawings. The disclosure comprises all such modifications and alterations and is limited only by the scope of the following claims. In particular regard to the various functions performed by the above described features (e.g., elements, resources, etc.), the terms used to describe such features are intended to correspond, unless otherwise indicated, to any features which performs the specified function of the described features (e.g., that is functionally equivalent), even though not structurally equivalent to the disclosed structure. In addition, while a particular feature of the disclosure may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application.

Examples or embodiments of the subject matter and the functional operations described herein can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them.

Some examples or embodiments are implemented using one or more modules of computer program instructions encoded on a computer-readable medium for execution by, or to control the operation of, a data processing apparatus. The computer-readable medium can be a manufactured product, such as hard drive in a computer system or an embedded system. The computer-readable medium can be acquired separately and later encoded with the one or more modules of computer program instructions, such as by delivery of the one or more modules of computer program instructions over a wired or wireless network. The computer-readable medium can be a machine-readable storage device, a machine-readable storage substrate, a memory device, or a combination of one or more of them.

The terms “computing device” and “data processing apparatus” encompass all apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. The apparatus can include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, a runtime environment, or a combination of one or more of them. In addition, the apparatus can employ various different computing model

infrastructures, such as web services, distributed computing and grid computing infrastructures.

The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output.

Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read-only memory or a random access memory or both. The essential elements of a computer are a processor for performing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto-optical disks, or optical disks. However, a computer need not have such devices. Devices suitable for storing computer program instructions and data include all forms of non-volatile memory, media and memory devices.

In the present specification “comprise” means “includes or consists of” and “comprising” means “including or consisting of”.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilized for realizing the invention in diverse forms thereof.

What is claimed is:

1. A hookah device for use with a hookah having an elongate stem and a water chamber with a first end of the stem attached to the water chamber, the hookah device comprising:

a plurality of ultrasonic mist generator devices which are each provided with a respective housing which comprises an air inlet port and a mist outlet port, a liquid chamber provided within the mist generator housing, the liquid chamber containing a liquid to be atomized, and a sonication chamber provided within the mist generator housing;

a driver device which is connected electrically to each of the plurality of mist generator devices to activate the mist generator devices, wherein each mist generator device is releasably attached to the driver device so that each mist generator device is separable as an individual unit from the driver device; and

a hookah attachment arrangement which attaches the hookah device to a second end of the stem of the hookah, the hookah attachment arrangement having a hookah outlet port which provides a fluid flow path from the mist outlet ports of the mist generator devices and out of the hookah device such that, when at least one of the mist generator devices is activated by the driver device, mist generated by each activated mist generator device flows along the fluid flow path and out of the hookah device to the hookah.

2. The hookah device of claim 1, wherein the driver device is connected electrically to each of the mist generator devices by a data bus and the driver device identifies and controls each mist generator device using a respective unique identifier for the mist generator device.

3. The hookah device of claim 1, wherein each mist generator device comprises:

an identification arrangement comprising:

an integrated circuit having a memory which stores a unique identifier for the mist generator device; and an electrical connection which provides an electronic interface for communication with the integrated circuit.

4. The hookah device of claim 1, wherein the driver device controls each respective mist generator device to activate independently of the other mist generator devices.

5. The hookah device of claim 4, wherein the driver device controls the mist generator devices to activate in a predetermined sequence.

6. The hookah device of claim 1, further comprising:

a manifold having a manifold pipe which is in fluid communication with the mist outlet ports of the mist generator devices, wherein mist output from the mist outlet ports combines in the manifold pipe and flows through the manifold pipe and out from the hookah device.

7. The hookah device of claim 6, wherein the hookah device comprises four mist generator devices which are releasably coupled to the manifold at 90° relative to one another.

8. A hookah device for use with a hookah having an elongate stem and a water chamber with a first end of the stem attached to the water chamber, the hookah device comprising:

a plurality of ultrasonic mist generator devices which are each provided with a respective mist outlet port, wherein each mist generator device comprises:

a mist generator housing which is elongate and comprises an air inlet port and the mist outlet port;

a liquid chamber provided within the mist generator housing, the liquid chamber containing a liquid to be atomized;

a sonication chamber provided within the mist generator housing;

a capillary element extending between the liquid chamber and the sonication chamber such that a first portion of the capillary element is within the liquid chamber and a second portion of the capillary element is within the sonication chamber;

an ultrasonic transducer having a generally planar atomization surface which is provided within the sonication chamber, the ultrasonic transducer being mounted within the mist generator housing such that the plane of the atomization surface is substantially parallel with a longitudinal length of the mist generator housing, wherein part of the second portion of the capillary element is superimposed on part of the atomization surface, and wherein the ultrasonic transducer vibrates the atomization surface to atomize a liquid carried by the second portion of the capillary element to generate a mist comprising the atomized liquid and air within the sonication chamber; and

an airflow arrangement which provides an air flow path between the air inlet port, the sonication chamber and the hookah outlet port;

a driver device which is connected electrically to each of the mist generator devices to activate the mist generator devices, wherein each mist generator device is releasably attached to the driver device so that each mist generator device is separable from the driver device; and

a hookah attachment arrangement which attaches the hookah device to a second end of the stem of the hookah, the hookah attachment arrangement having a



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hookah outlet port which provides a fluid flow path from the mist outlet ports of the mist generator devices and out of the hookah device such that, when at least one of the mist generator devices is activated by the driver device, mist generated by each activated mist generator device flows along the fluid flow path and out of the hookah device to the hookah.

9. The hookah device of claim 8, wherein each mist generator device further comprises:

a transducer holder which is held within the mist generator housing, wherein the transducer holder holds the ultrasonic transducer and retains the second portion of the capillary element superimposed on part of the atomization surface; and

a divider portion which provides a barrier between the liquid chamber and the sonication chamber, wherein the divider portion comprises a capillary aperture through which part of the first portion of the capillary element extends.

10. The hookah device of claim 8, wherein the capillary element is 100% bamboo fiber.

11. The hookah device of claim 8, wherein the airflow arrangement changes the direction of a flow of air along the air flow path such that the flow of air is substantially perpendicular to the atomization surface of the ultrasonic transducer the flow of air passes into the sonication chamber.

12. The hookah device of claim 8, wherein the liquid chamber contains a liquid having a liquid viscosity between 1.05 Pa·s and 1.412 Pa·s and a liquid density between 1.1 g/ml and 1.3 g/ml.

13. The hookah device of claim 8, wherein the liquid chamber contains a liquid comprising approximately a 2:1 molar ratio of levulinic acid to nicotine.

14. The hookah device of claim 1, wherein the driver device comprises:

an AC driver which generates an AC drive signal at a predetermined frequency to drive a respective ultrasonic transducer in each mist generator device;

an active power monitoring arrangement which monitors the active power used by the ultrasonic transducer when the ultrasonic transducer is driven by the AC drive signal, wherein the active power monitoring arrangement provides a monitoring signal which is indicative of an active power used by the ultrasonic transducer;

a processor controlling the AC driver and receiving the monitoring signal from the active power monitoring arrangement; and

a memory storing instructions which, when executed by the processor, cause the processor to:

A. control the AC driver to output an AC drive signal to the ultrasonic transducer at a predetermined sweep frequency;

B. calculate the active power being used by the ultrasonic transducer based on the monitoring signal;

C. control the AC driver to modulate the AC drive signal to maximize the

D. store a record in the memory of the maximum active power used by the ultrasonic transducer and the sweep frequency of the AC drive signal;

E. repeat steps A-D for a predetermined number of iterations with the sweep frequency incrementing with each iteration such that, after the predetermined num-

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ber of iterations has occurred, the sweep frequency has been incremented from a start sweep frequency to an end sweep frequency;

F. identify from the records stored in the memory the optimum frequency for the AC drive signal which is the sweep frequency of the AC drive signal at which a maximum active power is used by the ultrasonic transducer; and

G. control the AC driver to output an AC drive signal to the ultrasonic transducer at the optimum frequency to drive the ultrasonic transducer to atomize a liquid.

15. The hookah device of claim 14, wherein the active power monitoring arrangement comprises:

a current sensing arrangement which senses a drive current of the AC drive signal driving the ultrasonic transducer, wherein the active power monitoring arrangement provides a monitoring signal which is indicative of the sensed drive current.

16. The hookah device of claim 4, wherein the memory stores instructions which, when executed by the processor, cause the processor to:

repeat steps A-D with the sweep frequency being incremented from a start sweep frequency of 2900 kHz to an end sweep frequency of 2960 kHz.

17. The hookah device of claim 14, wherein the memory stores instructions which, when executed by the processor, cause the processor to:

repeat steps A-D with the sweep frequency being incremented from a start sweep frequency of 2900 kHz to an end sweep frequency of 3100 kHz.

18. The hookah device of claim 14, wherein the AC driver modulates the AC drive signal by pulse width modulation to maximize the active power being used by the ultrasonic transducer.

19. A hookah comprising:

a water chamber;

an elongate stem having a first end which is attached to the water chamber, the stem comprising a mist flow path which extends from a second end of the stem, through the stem, to the first end; and

a hookah device comprising:

a plurality of ultrasonic mist generator devices which are each provided with a respective housing which comprises an air inlet port and a mist outlet port, a liquid chamber provided within the mist generator housing, the liquid chamber containing a liquid to be atomized, and a sonication chamber provided within the mist generator housing;

a driver device which is connected electrically to each of the Plurality of mist generator devices to activate the mist generator devices, wherein each mist generator device is releasably attached to the driver device so that each mist generator device is separable as an individual unit from the driver device; and

a hookah attachment arrangement which is attached to the stem at the second end of the stem, the hookah attachment arrangement having a hookah outlet port which provides a fluid flow path from the mist outlet ports of the mist generator devices and out of the hookah device such that, when at least one of the mist generator devices is activated by the driver device, mist generated by each activated mist generator device flows along the fluid flow path, out of the hookah device, through the mist flow path in the stem and into the water chamber.

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

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INVENTOR(S) : Imad Lahoud et al.

Page 1 of 1


It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

Claim 11, Column 35, Line 26: change “transducer the flow of air passes into the sonication chamber” to --transducer as the flow of air passes into the sonication chamber--

Claim 14, Column 35, Lines 56-57: change “C. control the AC driver to modulate the AC drive signal to maximize the” to --C. control the AC driver to modulate the AC drive signal to maximize the active power used by the ultrasonic transducer--

Claim 16, Column 36, Line 19: change “The hookah device of claim 4” to --The hookah device of claim 14--

Signed and Sealed this  
Tenth Day of October, 2023  


Katherine Kelly Vidal  
*Director of the United States Patent and Trademark Office*